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Page 71, *read* Fig. 29 *for* left-hand figure, and Fig. 28 *for* right-hand figure.

Page 127, title, *read* 27 to December 30, 1927.

Page 141, the title to *read* A preliminary report on the relationship of insect barriers to the development of tip and margin burn of Irish potatoes *for* A preliminary report on the relationship of insect carriers, etc.

Page 215, line 8, *read* corms *for* corns.

Page 274, Table 7, the 2-column heading, *read* No manure | Manure *for* Manure | No manure.

Page 276, paragraph 4, line 2, *insert* in connection with proper soil moisture after good soil treatment.

Page 488, line 4, *read* Two *for* the.

Page 502, Entry 37, *omit* repeated matter.

Page 502, Entry 48, *read* potatos *for* potatoes [so in original].

Cover of July number, *read* E. F. Gaines *for* E. E. Gaines.

Page 572, legend for Fig. 4, *read* old culture *for* cold culture.

Page 664, line 1, *after* barley *insert* rust.

Page 676, Table 1, in column headed "Solution," opposite last entry for April 20, *read* emulsin *for* emulsion.

Page 699, line 8, *read* 10 gm. *for* 10 m.

Page 706, Table 1, under *U. macrosperma delete P. pubescens.*

Page 708, before last paragraph *insert* Note 9.

Page 832, line 16, *read* active *for* alive.

Page 839, line 26, *read* pure *for* parts.

Cover of November number, *read* H. K. Chen *for* K. H. Chen.

Page 919, line 21, *read* 36.3 *for* 26.6.

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CONTENTS OF VOLUME XVIII

NO. 1. JANUARY

PAGE

To Erwin Frink Smith 1

Biometrical studies on the variation of physiologic forms of Puccinia graminis tritici and the effects of ecological factors on the susceptibility of wheat varieties. MOSES N. LEVINE 7

Phytopathological Notes 125

Abstracts of papers presented at the nineteenth annual meeting of the American Phytopathological Society, Nashville, Tennessee, December 27 to 30, 1927 127

NO. 2. FEBRUARY

The control of teliospore and urediniospore formation by experimental methods. CHARLES W. WATERS 157

A mosaic disease of Gladiolus. LOUISE DOSDALL 215

Washingtonia palm leaf spot due to Cylindrocladium macrosporum n. sp. C. D. SHERBAKOFF 219

Constant temperature and humidity chambers. JAMES JOHNSON 227

Penicillium injury to corn seedlings. HELEN JOHANN 239

The crown elongation disease of the peony. H. H. WHETZEL 243

Phytopathological Notes 245

NO. 3. MARCH

Preliminary observations on sugar cane mycorrhizae and their relationship to root diseases. R. CIFERRI 249

Predisposition of sugar-beets to late rootrot. GEORGE STEWART and D. W. PITTMAN 263

The production of agglutinins by phytopathogenic bacteria. M. C. GOLDSWORTHY 277

Notes on the crowngall situation in England, France, and Holland. A. J. RIKER 289

Experiments on the control of barley stripe. H. A. RODENHISER 295

Club root in relation to soil alkalinity. CHARLES CHUPP 301

Varietal susceptibility of potatoes to Fusarium wilt and stem-end rot. R. W. GOSS 307

Phytopathological Notes 311

NO. 4. APRIL

Comparative studies of certain Cladosporium diseases of stone fruits. M. BENSAUDE and G. W. KEITT 313

A study of pathogenic and non-pathogenic strains of Pseudomonas tumefaciens Sm. and Town. M. K. PATEL 331

Physiologic specialization in Puccinia sorghi. E. C. STAKMAN, J. J. CHRISTENSEN, and H. E. BREWBAKER 345

The fungicidal action of liquid lime sulfur. M. C. GOLDSWORTHY 355

Comparative virulence of certain strains of Pythium in direct inoculation of conifers. E. J. ELIASON 361

The relation of temperature during the growing season in the spring wheat area of the United States to the occurrence of stem rust epidemics. E. C. STAKMAN and E. B. LAMBERT 369

NO. 5. MAY

Studies of the ascigerous stage of Venturia inaequalis (Cke.) Wint. in relation to certain factors of the environment. E. E. WILSON 375
A consideration of the pathogenicity of the cotton-wilt fungus, Fusarium vasinfectum. H. R. ROSEN 419
Strawberry dwarf. A. G. PLAKIDAS 439
Transmission of potato spindle-tuber by grasshoppers (Locustidae). R. W. GOSS 445
Copper sulphate as a remedy for exanthema in prunes, apples, pears, and olives. RALPH E. SMITH and HAROLD E. THOMAS 449
Classification of copper fungicides. E. B. HOLLAND and G. M. GILLIGAN 455
Phytopathological Notes 459
Report of the nineteenth annual meeting of the American Phytopathological Society 463
Report of the ninth annual meeting of the Canadian Division of the American Phytopathological Society 477

NO. 6. JUNE

Blight-resistant potatoes. DONALD REDDICK 483
Oleander bacteriosis in California. CLAYTON O. SMITH 503
Dry rot of Gladiolus corms. L. M. MASSEY 519
"Black tip," a finger-tip disease of the Chinese banana in Bermuda. LAWRENCE OGILVIE 531
Histology of the lesions produced by Sphaceloma fawcettii Jenkins on leaves of Citrus. H. S. CUNNINGHAM 539
Root and crown injury to apple trees. H. E. THOMAS 547

NO. 7. JULY

The migration of Bacterium tumefaciens in the tissue of tomato plants. J. BEN HILL 553
Some fungi of the Stemphylium type and their relation to apple rots. GEORGE A. NEWTON 565
New physiologic forms of Tilletia levis and T. tritici. E. F. GAINES 579
Influence of environmental factors on the seasonal prevalence of corn smut. F. R. IMMER and J. J. CHRISTENSEN 589
Determination of losses due to smut infections in selfed lines of corn. F. R. IMMER and J. J. CHRISTENSEN 599
The reactions of plant stems to fungous products. C. R. HURSH 603
A powdery mildew parasitizing Chinese cabbage. W. H. DAVIS 611
A field method of insuring positive attack with some cereal diseases. W. W. MACKIE 617
A possible alternate stage of Pucciniastrum myrtilli (Schum.) Arth. J. S. BOYCE 623

NO. 8. AUGUST

Owen F. Burger. GEORGE F. WEBER 627
The inheritance of resistance to Puccinia graminis tritici in a cross between two varieties of Triticum vulgare. C. H. GOULDEN, K. W. NEATBY, and J. N. WELSH 631
Progress of rust studies. J. C. ARTHUR 659

Transmission of the virus of curly-top of sugar beets through different solutions. WALTER CARTER 675
Filtration experiments on curly top of sugar beets. HENRY H. P. SEVERIN and OLIVE SWEZY 681
Preliminary note on some serological studies of Aspergilli. TAKASHI MATSUMOTO 691
Effects of mosaic upon the chlorophyll content of tobacco. ALBERT A. DUNLAP 697
An Ascomycetous leaf spot of cowpea. L. R. TEHON and G. L. STOUT 701
A conspectus of needle rusts on balsam firs in North America. J. S. BOYCE 705
Phytopathological Notes 709
Book Review 715

NO. 9. SEPTEMBER

A study of the histologic changes induced in leaves by certain leaf spotting fungi. H. S. CUNNINGHAM 717
Three Helminthosporium diseases of sugar cane. JAMES A. FARIS 753
The effect of a manganese deficiency on the sugar cane plant and its relationship to Pahala blight of sugar cane. H. ATHERTON LEE and J. S. MCHARGUE 775
Powdery mildew of raspberry. P. D. PETERSON and H. W. JOHNSON 787
Preliminary note on snowberry anthracnose. M. F. BARRUS and J. G. HORSFALL 797
The demonstration of bacteria in plant tissues by means of the Giemsa stain. WILLIAM H. WRIGHT and VLADIMIR SKORIC 803
Storage rots of cranberries in the 1927 crop. NEIL E. STEVENS and HENRY F. BAIN 809
Note on the occurrence of intracellular bodies in spike disease of sandal (Santalum album Linn.). M. J. NARASIMHAN 815

NO. 10. OCTOBER

Pathogenicity of Bacillus mesentericus, B. aroideae, B. carotovorus, and B. phytophthorus to potato tubers. PHILIP BRIERLEY 819
Preliminary studies of the life history of Erostrotheca multiformis, the perfect stage of Cladosporium album Dowson. G. HAMILTON MARTIN and VERA K. CHARLES 839
Control of cucumber powdery mildew in greenhouses. E. F. GUBA 847
The root-knot of abacá, or Manila hemp. GERARDO OFFIMARIA OCFEMIA and MELANIO R. CALINISAN 861
Differential staining of Peronosporaceae. E. LEPIK 869
Pythium arrhenomanes n. sp., a parasite causing maize root rot. CHARLES DRECHSLER 873

NO. 11. NOVEMBER

Flora W. Patterson. BEVERLY T. GALLOWAY 877
Phytophthora blight of peony. D. C. COOPER and C. L. PORTER 881
Localization of resistance to powdery mildew in the barley plant. JANE R. MACKIE 901
The effect of seed disinfectants on smut and on yield of millet. R. H. PORTER, T. F. YU, and H. K. CHEN 911
Control of bunt of wheat in Nebraska. GEORGE L. PELTIER 921
Endosepsis and its control in caprifigs. H. N. HANSEN 931
Development of storage diseases in sugar beets resulting from hook injury. C. M. TOMPKINS and S. B. NUCKOLS 939

Phytopathological Notes 943
Report of the twelfth annual meeting of the Pacific Division of the American Phytopathological Society 947

NO. 12. DECEMBER

Physiologic specialization in some cereal smuts. H. A. RODENHISER 955
On the occurrence of pycnia and aecia in certain rust fungi. J. H. CRAIGIE 1005
A simple apparatus for isolating single spores. W. F. HANNA 1017
Book Reviews 1023
Phytopathological Notes 1025

INDEX TO VOLUME XVIII

New species in blackface type

Abacá, root knot of, 861–867

Abies, amabilis, host of needle rusts, 705–708; arizonica, host of Peridermium pustulatum, 705–708; balsamea, host of needle rusts, 705–708; concolor, host of needle rusts, 705–708; fraseri, host of needle rusts, 705–708; grandis, host of needle rusts, 705–708; lasiocarpa, host of needle rusts, 705–708; magnifica, host of needle rusts, 705–708; nobilis, host of needle rusts, 705–708; species, conspectus of needle rusts on, 705–708; venusta, host of Peridermium pseudobalsameum, 705–708

Abstracts, of papers presented at the nineteenth annual meeting of the American Phytopathological Society, Nashville, Tenn., December 28, 1927, to January 1, 1928, 127–156; of papers read at the ninth annual meeting, Canadian Division of the American Phytopathological Society, 477–481

Acanthorhynchus vaccinii, causing cranberry storage rot, 809–814

Accuracy in comparing concentrations of tobacco-mosaic virus, 132

Acer, pennsylvanicum, lesions produced by Septoria acerina, 734; rubrum, lesions produced by Rhytisma acerinum, 744

Actinomycete, causing soil rot or pox in sweet potatoes, 152

ADAMS, J. F., An Actinomycete the cause of soil rot or pox in sweet potatoes, 152

Aecia, in simple (monosporidial) pustules, 1008–1010; occurrence of, in certain rust fungi, 1005–1015; occurrence under natural conditions of pycnia, unaccompanied by, 1010–1014; of white-pine blister rust, permanent mounts of, 1029

Aecial host, in relation to severity of stem-rust epidemics, 105–108

Aecidium, onobrichydis, 665; polygalinum, 665

Agar, carrot, for Pythium, 710

Agglutinins, production of, by phytopathogenic bacteria, 277–288

Alfalfa, white spot of, caused by irrigation, 136–137

Alkalinity, soil, clubroot in relation to, 301–306

Alternaria, citri, 949; solani, lesions produced on Lycopersicum esculentum, 740; solani, lesions produced on Solanum tuberosum, 739–740; sp., relation to apple rots, 565

American Phytopathological Society, abstracts of papers presented at Nashville meeting, Dec. 28, 1927, to Jan. 1, 1928, 127–156; Canadian Division, abstracts of papers read at, 477–481; report of nineteenth annual meeting, 463–474; report of ninth annual meeting Canadian Division, 477–481

Ampelopsis tricuspidata, lesions produced by Guignardia bidwellii, 746–747

ANDERSON, H. W., Bacteriophage of Bacterium pruni, 144

ANDERSON, P. J., Soil reaction and black root rot of tobacco, 131

Andropogon, rust on, 665

Angular leaf spot, 951

Antheridia, paragynous, of Phytophthora spp., 149–150

Anthracnose of snowberry, 797–801

Antirrhinum majus, Puccinia antirrhini on, experimental control of teliospore and urediniospore formation, 176–178, 183–184, 192–194

Antiserum, production of, against phytopathogenic bacteria, 278–288

Aphanomyces, cochlioides, n. sp., on sugar beets in the United States, 149; euteiches, pathogenicity for conifers, 366

Aphis, transmission of cucumber mosaic, 143

Apium graveolens, lesions produced by Septoria petroselini, 731

Aplanobacter stizolobii, see Bacterium stizolobii, 460

Apparatus, constant-temperature and humidity chambers, 227–238; for isolating single spores, 1017–1021

Apple, and quince trees, nursery, overgrowths and hairy root on, 127; blotch, cycle of infection in, 145; correlation of the wound overgrowth and crown gall of, 128; grafting as a further means of preventing callus knots on, 127–128; grafts, history of development of wound overgrowths on, and of the influence of wrappers on their suppression, 128; root and crown injury, to trees, 547–551; rots, caused by some fungi of the Stemphylium type, 565–578; scab, control with certain sulphur fungicides, 146–147; scab of, fall applications of fungicides in relation to control of, 146; scab, see Venturia inaequalis; sporotrichum fruit spot of, 145; studies of black root of, 145

Apples, copper sulphate as remedy for exanthema in, 449–454

Apricot, scab caused by Cladosporium, 314–315

Armillaria mellea in mines and wells, 948

ARTHUR, J. C., Progress of rust studies, 659–674

Asci, apple scab, effect of environment upon, 375–418

Ascomycetous leaf spot of cowpea, 701–704

Asparagus officinale, Puccinia asparagi on, experimental control of teliospore and urediniospore formation, 180, 181–183

Aspergilli, investigations of, by serological methods, 148; serological studies of, 691–696

Aspergillus, attacking mealybugs in insectaries in southern California, 948; niger, 949; niger, reaction of plant stems to the products of, 604–605

Aster, China, Fusarium wilt of, 150; yellows, studies on host range of, 156

Asterocystis racidis, 949–950

Athyrium cyclosorum, host of Uredinopsis copelandi, 705–708

Attenuation of plant viruses, 156

Bacillus, aroideae, humidity relations of, 827–829; aroideae, inoculation into various hosts, 832–836; aroideae, pathogenicity to potato tubers, 819–838; aroideae, temperature relations of, 822–827; carotovorus, humidity relations of, 827–829; carotovorus, inoculation into various hosts, 832–836; carotovorus, pathogenicity to potato tubers, 819–838; carotovorus, temperature relations of, 822–827; mesentericus, humidity relation of, 827–829; mesentericus, inoculation into various hosts, 832–836; mesentericus, pathogenicity to potato tubers, 819–838; mesentericus, temperature relations of, 822–827; phytophthorus, humidity relations of, 827–829; phytophthorus, inoculation into various hosts, 832–836; phytophthorus, pathogenicity to potato tubers, 819–838; phytophthorus, temperature relations of, 822–827; tracheiphilus, methyl violet for staining, 803–807

Bacteria, demonstration in plant tissues by means of Giemsa stain, 803–807; phytopathogenic, production of agglutinins by, 277–288

Bacterial, disease of broad beans, 136; redstripe disease of sugar cane in countries of the Pacific, 945

Bacteriophage of Bacterium pruni, 144

Bacteriosis of Oleander in California, 503–518

Bacterium, cerasus, 952; citriputeale, 952; **maculicola,** (McC.) nom. emend. syn. Bact. maculicolum, 460; maculicolum, production of antisera against, 278–288; maculicolum, see Bact. maculicola; pruni, bacteriophage of, 144; **stizolobii** (Wolf), comb. nov. syn. Aplanobacter stizolobii, 460; syringae, 952; tumefaciens, biology, 332–339; tumefaciens, distribution in nature, 339–342; tumefaciens, method and rate of migration in tomato, 129; tumefaciens, migration in tissue of tomato plants, 553–564; tumefaciens, see Pseudomonas tumefaciens

BAILEY, D. L., and F. J. GREANEY, see GREANEY, F. J.; Sulphur dusting for the control of leaf and stem rust in Manitoba: Field trials with horse-drawn and aeroplane dusters, 480

BAIN HENRY F., see STEVENS, NEIL E.

Balsam firs, conspectus of needle rusts on, 705–708

Banana, Chinese, "finger-tip" disease, 531–538

BANFIELD, W. M., see RIKER, A. J.; Studies on the life history of the crown-gall organism, 128–129

Barley, control of stripe disease, 477–478; dwarf leaf rust of, in western Canada, 481; hullness, control of covered smut and stripe on, 139; plant, powdery mildew, 901–910; stripe, experiments on control of, 295–300

BARRETT, J. T., Phytophthora in relation to crown rot of walnut, 948–949

BARRUS, M. F., and JAMES G. HORSFALL, Preliminary note on snowberry anthracnose, 797–801

BARSS, H. P., A question of correct usage, 460

Bean, mosaic of, transmission, 155; susceptibility to Bacillus carotovorus, B. phytophthorus, and B. aroideae, 834–835; Uromyces appendiculatus on, experimental control of teliospore and urediniospore formation, 163–169, 183, 184–187, 206

Beans, broad, a bacterial disease of, 136

Beech, mottle-leaf disease of, 151–152

BEECHER, F. S., Measurements of total daily sunlight intensity with reference to the ecology of plant diseases, 951; see SHAPOVALOV, M.

Beet, curly top, on celery and spinach, 709–710; sugar, predisposition of, to late root rot, 263–276; sugar, transmission of curly-top virus through different solutions, 675–679

Beets, sugar, filtration experiments on curly top of, 681–690

BENSAUDE, M., and G. W. KEITT, Comparative studies of certain Cladosporium diseases of stone fruits, 313–329

Beta, vulgaris, 939; lesions produced by Cercospora beticola, 728–730

BIJL, P. A. van der, Plantsiektes hul oorsaak en bestryding, review of, 1023

Biography, of BURGER, OWEN F., 627–630

Biology, life history of Erostrotheca multiformis, perfect stage of Cladosporium album, 839–846; life history of Sclerotium gladioli, 526–527; of Bacterium tumefaciens, 332–339

Biometrical studies on the variation of physiologic forms of Puccinia graminis tritici and the effects of ecological factors on the susceptibility of wheat varieties, 7–123

BISHOP, C. J., see DAVIS, A. R.

Black leg, potato, transmisison by seed-corn maggot, 459

Back scab, or warty disease, of potato, in Belgium, 126

"Black tip," disease of Chinese banana, 531–538

Blast, citrus, 952; in oats, 948

Blastophaga psenes, 931–932, 938

Blight, brown, disease of lettuce, 949; fire, disinfectants in eradication work, 710–711; Pahala, of sugar cane, effect of manganese deficiency on, 775–786; Phytophthora of peony, 881–900; seedling, of oats, 480; thread, further observations on, 147–148; tip caused by Phytophthora, 882–883

Blight-resistant potatoes, 483–502

Blister rust of white pine, see Cronartium ribicola

BLOOD, H. L., A "streak" of tomatoes produced by a disturbing principle from apparently healthy potatoes in combination with tomato mosaic virus, 311

Blotch, of apple, cycle of infection in, 145

BONDE, REINER, The transmission of potato black leg by the seed-corn maggot in Maine, 459

Book review, Die Krankheiten der Obstbäume und Obststräucher, by E. EWERT, 715; A list of Japanese fungi hitherto unknown, 1023; Plantsiektes hul oorsaak en bestryding, 1023

Bordeaux mixture, preventing stem rot of sweet potatoes, 152–153

Botrytis, 881

BOYCE, A. M., and H. S. FAWCETT, An Aspergillus attacking mealybugs in insectaries in southern California, 948

BOYCE, J. S., A conspectus of needle rusts on balsam firs in North America, 705–708; A possible alternate stage of Puc-

ciniastrum myrtilli (Schum.) Arth., 623–625

BOYD, O. C., Comparison of various disinfectants in the treatment of sweet potatoes for black-rot control, a progress report, 153–154; Preliminary report on a new leaf spot of pecan, 133–134

BREWBAKER, H. E., see STAKMAN, E. C.

BRIERLEY, PHILIP, Pathogenicity of Bacillus mesentericus, B. aroideae, B. carotovorus, and B. phytophthorus to potato tubers, 819–838

BROWN, A. M., and M. NEWTON, The dwarf leaf rust of barley in western Canada (Puccinia anomala Rostr.), 481; see NEWTON, M.

BROWN, H. D., see STAIR, E. C.

BROWN, J. G., The influence of sodium chloride in alkali soils on the susceptibility of Pima cotton to angular leaf spot caused by Phytomonas malvacera, 951

Brown rot, 931

Brown stripe, of sugar cane, 761–772; of sugar cane, caused by **Helminthosporium stenospilum**, n. sp., 135–136; of sugar cane, in Cuba, 135

BRYAN, MARY K., Verticillium wi't of heliotrope, 246

Bulbs, of ornamental plants, condition of, offered for importation into Canada, 150–151

Bunchy top, of abacá, relation of Heterodera radicicola to, 865–866

Bunt, effect of washing seed on infection, 711–713; infection, influence of soil temperature and moisture, 924–928; of wheat, control, in Nebraska, 921–929

BURGER, OWEN F., biography of, 627–630

Cabbage, Chinese, parasitized by a powdery mildew, 611–615; Fusarium-resistant, Jersey Wakefield type, 142; Iacope, improvement of, by selecting and selling, 142; susceptibility to Bacillus carotovorus, B. phytophthorus, and B. aroideae, 833–835

Caeoma americana, on Abies species, 705–708

CALINISAN, MELANIO R., see OCFEMIA, GERARDO OFFIMARIA

Calyptospora, columnaris, on Vaccinium species, 705–708; sp., on V. macrophyllum, 705–708

Canadian Division, American Phytopathological Society, report of ninth annual meeting of, 477–481

Cane, sugar, observations on mycorrhizae and their relation to root diseases of, 249–261; sugar, see sugar cane.

Capsicum sp., mosaic of, in West Africa, 155

Carrot, agar, for Pythium, 710; susceptibility to Bacillus carotovorus, B. aroideae, B. phytophthorus, 832–835

CARSNER EUBANKS, and C. F. LACKEY, Further studies on attenuation of the virus of sugar beet curly top, 951

CARTER, WALTER, An improvement in the technique for feeding homopterous insects, 246–247; Transmission of the virus of curly top of sugar beets through different solutions, 675–679

CATION, DONALD, see HOWE, MARY F.

Cauliflower, spot disease of, 460

Caulophyllum thalictroides, lesions produced by Cercospora caulophylli, 735

Celery, host of beet curly top, 709–710

Cerastium species, alternate host of a fir needle rust, 705–708

Cercospora, beticola, lesions produced on Beta vulgaria, 728–730; caulophylli, lesions produced on Caulophyllum thalictroides, 735; circumcissa, lesions produced on Prunus serotina, 737–738; menispermi, lesions produced on Menispermum canadense, 736–737; musarum, cause of "finger-tip" or "black tip" of Chinese banana, 533–536; symplocarpi, lesions produced on Symplocarpus foetidus, 736

Cereal, diseases, field method of insuring positive attack by, 617–621; smuts, physiologic specialization in, 955–1003

Cereals, diseases of, in Alberta, 481

Ceuthospora lunata, causing cranberry storage rot, 809–814

Chaleas exotica, 952

Changes, histologic, induced in leaves by leaf-spotting fungi, 717–751

CHARLES, V. K., see MARTIN, G. HAMILTON

CHEN, H. K., see PORTER, R. H.

Chenopodium murale, 951
Cherry, scab caused by Cladosporium, 315–316
Chinese cabbage, powdery mildew parasitizing, 611–615
Chlorophyll content, tobacco, effects of mosaic upon, 697–700
CHRISTENSEN, J. J., see IMMER, F. R.; see STAKMAN, E. C.
Chromosome, number, and reaction to rust and mildew in Linum, 478
CHUPP, CHAS., Clubroot in relation to soil alkalinity, 301–306
CHURCH, MARGARET B., and MARIO SCANDIFFIO, Phytophthora, Pythium, and Pythiacystis species as stock cultures, 247–248
Cicatrice, diseases in which it is definitely formed about margin of lesion, 723–731; diseases in which it is not definitely formed about edge of lesions, 731–747
Cicinnobolus cesatii, parasite of Sphaerotheca humuli on raspberry, 789
CIFERRI, R., Preliminary observations on sugar cane mycorrhizae and their relation to root diseases, 249–261
Cirsium arvense, lesions produced by Septoria cirsii, 733; Puccinia suaveolens on, experimental control of teliospore and urediniospore formation, 169–172, 191–192, 206
Citrus, aurantium, 953; blast and some allied organisms, 952; leaves, histology of lesions due to Sphaceloma fawcetii Jenkins, 539–545; limonia, 953
Cladosporium, album, life history of, 839–844; carpophilum, 328, 946; cerasi, see Venturia cerasi; cultural morphology, 324–327; diseases, 946; diseases of stone fruits, 313–329; of tomato, control by means of forced ventilation in hotbeds, 1027–1029; strains affecting stone fruits, 327–328; temperature relations, 322–324
Climatic conditions, effect on mycorrhizae, 258–259; in relation to severity of stem-rust epidemics, 91–105
Clover, Uromyces trifolii on, experimental control of teliospore and urediniospore formation, 172–175, 188–191, 206
Clubroot, of crucifers, reaction and treatment of soils infested with Plasmodiophora brassicae, 141–142; in relation to soil alkalinity, 301–306
Coccomyces, hiemalis, lesions produced on Prunus avium, 727; hiemalis, lesions produced on Prunus cerasus, 726–727; lutescens, lesions produced on Prunus virginiana, 725–726; prunophorae, lesions produced on Prunus domestica, 723–725
Collection, photographic, of ERWIN F. SMITH, 312
Comandra, rust on, 665
Conifers, seedling damping off, 361–367
Conspectus of needle rusts on balsam firs in North America, 705–708
Control, bunt of wheat, in Nebraska, 921–929; of apple scab in relation to fall applications of fungicides, 146; of apple scab, with certain sulphur fungicides, 146–147; of barley stripe, 477–478; of barley stripe, experiments, on, 295–300; of "black tip" of Chinese banana, 536–537; of covered smut and stripe of barley by seed disinfectants, 139; of cucumber powdery mildew in greenhouses, 847–860; of dry rot of Gladiolus corms, 527–528; of tomato Cladosporium and Septoria in hotbeds, by means of forced ventilation, 1027–1029; of true tobacco mosaic, 132; of turf diseases, with mercury, 137
COOK, MELVILLE T., The gummosis of sugar cane, 135
COOPER, D. C., and C. L. PORTER, Phytophthora blight of peony, 881–900
COOPER, DELMER, Paragynous antheridia of Phytophthora spp., 149–150
Copper, fungicides, classification of, 455–458; sulphate, remedy for exanthema in prunes, apples, pears, and olives, 449–454
Coprosma baueri, 952
Corm, of Gladioli, Penicillium rot of, 151; rot of Gladiolus caused by a Penicillium, 151
Corms of ornamental plants, condition of, offered for importation into Canada, 150–151
Corn, influence of environmental factors on prevalence of smut in, 589; losses due to

smut, 599–602; method of measuring efficiency of seed disinfectants on, 140; Penicillium injury to seedlings, 239–242; Puccinia sorghi on, experimental control of teliospore and urediniospore formation, 179–180, 194–195, 206; rust of, Puccinia sorghi, 345–354

Correlation of the wound overgrowth and crown gall of apple in parts of Europe and of the United States, 128

Corticium koleroga, further observations on, 147–148

Cotton, outstanding wilt-resistant varieties of, 134; seed treatment by the dusting method, 134; wilt fungus, consideration of the pathogenicity of, 419–438

Cowpea, ascomycetous leaf spot of, 701–704

CRAIGIE, J. H., Heterothallism in the rust fungi, 147; On the occurrence of pycnia and aecia in certain rust fungi, 1005–1015; Sexual behaviour of Puccinia graminis, 479

Cranberries, storage rots, in 1927, 809–814

Cronartium, cerebrum, 671; ribicola, permanent mounts of aecia of, 1029

Cropping systems of fertilizers, influence of, on black and brown root rot of tobacco, 131

Crown, and root injury to apple trees, 547–551; elongation disease of peony, 243–244; rot of walnut, 948–949

Crown gall, of apple, correlation of, and wound overgrowth, 128; organism, studies on the life history of, 128–129; situation in England, France, and Holland, notes on, 289–294; transplants, studies on, 130

Cucumber, Chinese, resistant to mosaic, 143; control of powdery mildew on, 847–860; fruit rot and angular leaf spot, 133; mosaic, transmission of, by aphis, 143; susceptibility to Bacillus aroideae, 834–835

Cucumis melo, lesions produced by Macrosporium cucumerinum, 740–741

Cultural, characteristics, Pseudomonas savastanoi var. nerii, 513–515; characters of Sclerotium gladioli, 524–526; conditions, effect of, on stability of physiologic forms of Puccinia graminis tritici, 108–113; differences, between physiologic forms of cereal smuts, 958–972; studies of Cladosporium strains, 325–327

Cultures, stock, of Phytophthora, Pythium, and Pythiacystis, 247–248

CUNNINGHAM, H. S., A study of histologic changes induced in leaves by certain leaf-spotting fungi, 717–751; Histology of the lesions produced by Sphaceloma fawcettii Jenkins on leaves of Citrus, 539–545

Curly top, of sugar beet, 951; of sugar beet, transmission of virus through different solutions, 675–679; of sugar beets, filtration experiments on, 681–690; tomato, 709–710

Cuscuta gronovii, haustorium of, 478

Cycle of infection in apple blotch, 145

Cylindrocladium macrosporum, n. sp., cause of leaf spot of Washingtonia palm, 219–225

Cytological, phenomena in disease-resistant plants, 144; studies of plant tissues affected with mosaic diseases, 154

DAHL, A. S., see MONTEITH, JOHN, JR.

Damping off, of coniferous seedlings, 361–367

Dandelion, Puccinia taraxaci on, experimental control of teliospore and urediniospore formation, 175–176, 196–197

DAVIS, A. R., R. H. MARLOTH, and C. J. BISHOP, The inorganic nutrition of the fungi. I. The relation of calcium and boron to growth and spore formation, 949

DAVIS, W. H., A powdery mildew parasitizing Chinese cabbage, 611–615; Two physiological forms of Ustilago striaeformis (Westd.) Niessl., 149

Development of tomato yellows under different light conditions, 950

Dieback, see exanthema

DIETZ, S. M., and L. D. LEACH, The effective methods of eradicating Rhamnus species susceptible to Puccinia coronata Corda, 138

Diplodia natalensis, 949

Disease, bacterial, of broad beans, 136; crown elongation of peony, 243–244; mottle-leaf, of beech, 151–152; of potato, new and destructive, in Utah, and its relation to the potato psylla, 140–141; spike, of Santalum album and Vinca rosea, occurrence of intracellular bodies in, 815–817; warty, or black scab, of potato, in Belgium, 126

Diseases, cereal, field method of insuring positive attack, 617–621; Cladosporium, of stone fruits, 313–329; mosaic, cytological studies of plant tissues affected with, 154; of cereals, in Alberta, 481; of turf, controlled with mercury, 137; virus, of tobacco in Kentucky, 132–133

Disinfectants, controlling sweet-potato black rot, 153–154; effect of, upon germination of seeds in storage for indefinite periods after treatment, 136; in fire-blight-eradication work, 710–711; of seed corn, method of measuring relative efficiency, 140; seed, for control of covered smut and stripe of barley, 139

DOAK, K. D., The mycorrhizal fungus of Vaccinium, 148

DOOLITTLE, S. P., Soil transmission of tomato mosaic and streak in the greenhouse, 155; and M. N. WALKER, Aphis transmission of cucumber mosaic, 143

DORAN, W. L., Effect of timothy infusion of different ages on the growth of tobacco and on brown root rot of tobacco, 131–132

DOSDALL, LOUISE, A mosaic disease of Gladiolus, 215–217

Dothiorella, ribis, 949; sp., 949

DRAYTON, F. L., Progress report on the condition of bulbs and corms of ornamental plants offered for importation into Canada, 150–151

DRECHSLER, CHARLES, The occurrence of **Aphanomyces cochlioides**, n. sp., on sugar beets in the United States, 149; **Pythium arrhenomanes**, n. sp., a parasite causing maize root rot, 873–875; A species of Helminthosporium distinct from H. sacchari, causing brown stripe of sugar cane, 135–136

Dry rot of Gladiolus corms, 519–529

Dryopteris, marginalis, host of Milesia marginalis, 705–708; spinulosa, host of M. kriegerina, 705–708

DUFRÉNOY, J., Cytological studies of plant tissues affected with mosaic diseases, 154; Some cytological phenomena in disease-resistant plants, 144

DUNLAP, ALBERT A., Effects of mosaic upon the chlorophyll content of tobacco, 697–700

Dust treatments for oat smuts, 139

Dusting, cotton-seed, 134

Dwarf, disease of strawberry, 439–444

Ecological factors, effects of, on susceptibility of wheat varieties to stem rust, 81–108

Edaphic conditions, effect on mycorrhizae, 258–259; in relation to severity of stem-rust epidemics, 90–91

Effect, of disinfectants upon the germination of seeds kept in storage for indefinite periods after treatment, 136; of manganese deficiency on sugar-cane plant and its relationship to Pahala blight of sugar cane, 775–786; of mixed inoculations of certain citrus fruit-rotting organisms, 949; of washing the seed on infection of wheat by stinking smut, 711–713

Effective methods of eradicating Rhamnus species susceptible to Puccinia coronata Corda, 138

Effects of lime on cigar tobacco, 130–131; of mosaic upon the chlorophyll content of tobacco, 697–700

ELIASON, E. J., Comparative virulence of certain strains of Pythium in direct inoculation of conifers, 361–367

ELMER, O. H., Penicillium corm rot of Gladioli, 151

Endophytes, taxonomy of sugar cane mycorrhizal, 251–256

Endosepsis, 931; and its control in caprifigs, 931–938

England, crown gall situation in, 289–294

Environment, influence of, in apple scab, 375–418; influence of, on seasonal prevalence of corn smut, 589–598

Eocronartium musicola, 952; fr. in a new locality and on a new host, 952
Epidemics, of stem rust, effect of ecological factors on, 81–108
Epidemiology, prevalence and distribution of physiologic forms of cereal smuts, 958–959, 997–999; prevalence and distribution of physiologic forms of Puccinia graminis tritici isolated from uniform rust nurseries in 1919–1923, 35–40; wheat stem rust, 369–374
Epilobium species, alternate hosts of fir-needle rusts, 705–708; hosts of Pucciniastrum epilobii, 705–708
Epiphytotics, see epidemiology
Eradicating species of Rhamnus, 138
Eradication, fire-blight, disinfectants in, 710–711
Eriksson prizes, announcement of, 1029-1030
Erostrotheca, multiformis, cultural studies of, 841–843; multiformis, life history of, 839–846
Errata, correction for "Virus mixtures that may not be detected in young tobacco plants," by H. H. McKinney, Phytopath. *16*: 893, 313
Erysiphaceae, 902
Erysiphe, cichoracearum, 904; cichoracearum, control of, 847–860; graminis, 901–904, 909; graminis, method of epidemic induction, 617–621; polygoni, parasitizing Chinese cabbage, 611–615
Etiology, of abacá root knot, 863–865; of decay in apples, 576; of dry rot of Gladiolus, 521–524; of Oleander bacteriosis, 512–513
Euonymus japonicus, 904
Euttetix tenellus, carrier of sugar-beet root rot, 263; transmission of sugar-beet curly top by, 675–679, 681–690
Ewert, E., Die Krankheiten der Obstbäume und Obststräucher, book review, 715
Exanthema, copper sulphate as remedy for, in prunes, apples, pears, and olives, 449–454
Experimental work with the transmission of bean mosaic, 155
Experiments, and observations on the control of true tobacco mosaic, 132; on control of barley stripe, 295–300; with tomato streak, 154
Eye-end rot, 931
Eye spot of sugar cane, caused by Helminthosporium sacchari, 135–136; H. ocellum causes, 757–761, 763–774; in Cuba, 135

Factors important in the development of perithecia of Venturia inaequalis, 145–146
Fajardo, T. G., Progress on experimental work with the transmission of bean mosaic, 155
Fall applications of fungicides in relation to apple-scab control, 146
Faris, James A., Brown stripe of sugar cane in Cuba, 135; Sugar-cane eye spot in Cuba, 135; Three Helminthosporium diseases of sugar cane, 753–774
Fawcett, H. S., see Boyce, A. M.; see Savastano, G.
Felix bulbifera, host of Uredinopsis copelandi, 705–708
Fertilizers and cropping systems, influence of, on black and brown root rot of tobacco, 131
Field meeting, Southern Section, American Phytopathological Society, notice of, 460
Filtration experiments on curly top of sugar beets, 681–690
"Finger-tip," disease of Chinese banana, 531–538
Fire blight, disinfectants in eradication work, 710–711
Firs, balsam, conspectus of needle rusts on, 705–708
Fisk, Vernon C., see Melhus, I. E.
Forced ventilation as a means of controlling tomato Cladosporium and Septoria in hotbeds, 1027–1029
Fragaria virginiana, lesions produced by Mycosphaerella fragariae, 744
France, crown-gall situation in, 289–294
Fraxinus, americana, lesions produced by Phyllosticta fraxinii, 741; floribunda, 952

FROMME, F. D., The effect of washing the seed on infection of wheat by stinking smut, 711–713; see WINGARD, S. A.; Studies of black root rot of apple, 145
Fruit rot, of cucumber, and angular leaf spot, 133
Fruit-rotting organisms, 949
Fruit spot, sporotrichum, of apple, 145
Fruits, stone, Cladosporium diseases, 313–329
Fungi, inorganic nutrition of, 949; leaf-spotting, histologic changes induced in leaves by, 717–751; rust, occurrence of pycnia and aecia in, 1005–1015
Fungicidal, activity, of sulphur, increased by oxidizing agents, 1026–1027; property of sulphur, factors affecting, 147
Fungicides, certain sulphur, in control of apple scab, 146–147; copper, classification of, 455–458; fall applications of, in relation to apple-scab control, 146; lime-sulphur, action, 355–360
Fungous products, reaction of plant stems to, 603–610
Furfural, penetration of, in plant tissues, 152
Further studies on attenuation of the virus of sugar-beet curly top, 951
Fusaria in the herbarium of Pathological Collections, B. P. I., U. S. Dept. Agr., 148–149
Fusarium, 941; batatatis, sweet-potato stem rot prevented by Bordeaux mixture, 152–153; culmorum, on oat seedlings, 480; eumartii, varietal susceptibility of potatoes to, 307–309; lycopersici, reaction of plant stems to products of, 604–605; moniliforme var. fici, 931, 936, 938; niveum, cause of watermelon wilt, 143–144; niveum, varietal resistance of watermelons to, 144; sp., 952; **tumidum,** n. sp., on Sorothamnus scoparius, 148; vasinfectum, pathogenicity of, 419–438; wilt and stem-end rot, varietal susceptibility of potatoes to, 307–309; wilt of China aster, 150
Fusarium-resistant cabbage of Jersey Wakefield type, 142
Fusicoccum, fraxini (Kabat. et Bulak), n. com., on Fraxinus excelsior, 148; putrefaciens, cause of cranberry storage rot, 809–814

GAINES, E. F., New physiologic forms of Tilletia levis and T. tritici, 579–588; New physiologic forms of T. tritici in wheat, 139
GALLOWAY, BEVERLY T., FLORA W. PATTERSON, 1847–1928, 877–879
GARDNER, MAX W., Sporotrichum fruit spot of apple, 145
Germination, effect of disinfectants upon, of seeds kept in storage, 136; of Puccinia glumarum, optimum temperature for, 481
Gibberella quinqueseptata, n. sp., on Cannabis sativa, 148
Giemsa stain, demonstration of bacteria in plant tissues by means of, 803–807
GILLIGAN, G. M., see HOLLAND, E. B.
Gladioli, Penicillium corm rot of, 151
Gladiolus corms, dry rot, 519–529; mosaic disease of, 215–217
Glomerella rufomaculans, causing cranberry storage rot, 809–814
Gnomonia leptostyla, lesions produced on Juglans cinerea, 746
GOLDSWORTHY, M. C., The fungicidal action of liquid lime sulphur, 355–360; Production of agglutinins by phytopathogenic bacteria, 277–288
GORDON, W. L., Physiologic forms of Puccinia graminis avenae Eriks. & Henn., in Canada, 479–480
GOSS, R. W., Transmission of potato spindle tuber by grasshoppers (Locustidae), 140, 445–448; Varietal susceptibility of potatoes to Fusarium wilt and stem-end rot, 307–309
GOULDEN, C. H., K. W. NEATBY, and J. N. WELSH, The inheritance of resistance to Puccinia graminis tritici in a cross between two varieties of Triticum vulgare, 631–658
Grafting, as a further means of preventing callus knots on apple, 127–128
Grafts, apple, history of development of wound overgrowths on and of the influence of wrappers on their suppression, 128

Grasshopper (Locustidae), transmitting potato spindle tuber, 140
Grasshoppers, transmission of potato spindle tuber by Locustidae, 445–448
Grated carrot agar favorable for studies of Pythium, 710
GREANEY, F. J., and D. L. BAILEY, see BAILEY, D. L.; Sulphur dusting for the control of leaf and stem rust in Manitoba: Winnipeg small-plot experiments, 480
GUBA, E. F., Control of cucumber powdery mildew in greenhouses, 847–860
Guignardia, bidwellii, lesions produced on Ampelopsis tricuspidata, 746–747; vaccinii, causing cranberry storage rot, 809–814
Gummosis of sugar cane, 135
GUTERMAN, E. F., Preliminary report on mechanical transmission of the mosaic of Lilium auratum, 1025–1026
Gymnoconia interstitialis, 671
Gymnosporangium sp., heterothallism in, 1005–1015

Hairy root, and overgrowths, on nursery-apple and quince trees, 127
HAMILTON, J. M., and G. W. KEITT, Certain sulphur fungicides in the control of apple scab, 146–147
HANNA, W. F., A simple apparatus for isolating single spores, 1017–1021
Hansen, Emil Ch., Medal, 1928, 125
HANSEN, H. N., Endosepsis and its control in caprifigs, 931–938
HARA, K., see SHIRAI, M.
Haustorium of Cuscuta gronovii, 478
Heliotrope, Verticillium wilt of, 246
Helminthosporiose of sugar cane, 754–758
Helminthosporium, diseases, three, of sugar cane, 753–774; gramineum, experiments on control of, 295–300; **ocellum**, n. sp., causing eye spot of sugar cane, 757–761, 763–772; sacchari, causing helminthosporiose of sugar cane, 754–758; sacchari, the cause of eye spot of sugar cane, 135–136; sativum, method of epidemic induction, 617–621; stenospilum, causing brown stripe of sugar cane in Cuba, 761–772; **stenospilum**, n. sp., causing brown stripe of sugar cane, 135–136; teres, method of epidemic induction, 617–621
Hemp, Manila, root knot of, 861–867
HENRY, A. W., Reaction of Linum species of various chromosome numbers to rust and powdery mildew, 478
Heterodera radicicola, description, 863–865; on abacá, 861–867; relation to bunchy top of abacá, 865–866
Heteroecism, a possible alternate stage of Pucciniastrum myrtilli, 623–625
Heterothallism, evidence of, in Puccinia graminis, 1005–1008; in certain rust fungi, 1005–1015; in the rust fungi, 147
HIENTON, T. E., see STAIR, E. C.
HILL, J. BEN, The method and rate of migration of Bacterium tumefaciens in tomato, 129; The migration of Bact. tumefaciens in the tissue of tomato plants, 553–564
Histologic changes induced in leaves by leaf-spotting fungi, 717–751
Histology of scab lesions on Citrus leaves, 539–545
Holland, crown-gall situation in, 289–294
HOLLAND, E. B., and G. B. GILLIGAN, Classification of copper fungicides, 455–458
HOLMES, FRANCIS O., Accuracy in comparing various concentrations of tobacco-mosaic virus, 132; Monochromatic light photography in the study of mosaic diseases, 154
Hordeum vulgare, 905
HORSFALL, JAMES G., see BARRUS, M. F.
Host, range, see parasitism
Hotbeds, forced ventilation as a means of controlling tomato Cladosporium and Septoria in, 1027–1029
HOTSON, J. W., Armillaria mellea in mines and wells, 948; Rusts of the Pacific Northwest, 948
HOWARD, FRANK L., Disinfectants in fire-blight-eradication work, 710–711
HOWE, MARY F., and DONALD CATION, The penetration of furfural in plant tissues, 152
HOWITT, J. E., and R. E. STONE, Results

of experiments on the control of barley stripe, 477–478
Humidity, chambers, constant-control, 227–238; effect of, on bacterial tuber rots, 827–829
HUNTER, H. A., see JEHLE, R. A.
HURSH, C. R., The reactions of plant stems to fungous products, 603–610
Hyalopsora aspidiotus, on Phegopteris dryopteris, 705–708
Hylemyia cilicrura, transmission of potato black leg by, in Maine, 459
Hypnaceae, 952

Ilex verticillata, lesions produced by Rhytisma ilices-canadensis, 743
IMMER, F. R., and J. J. CHRISTENSEN, Determination of losses due to smut infections in selfed lines of corn, 599–602; Influence of environmental factors on the seasonal prevalence of corn smut, 589–598
Infection, cycle of, in apple blotch, 145; of wheat by stinking smut, effect of washing the seed upon, 711–713
Inheritance of resistance, to blast in oats, 948; to Puccinia graminis tritici in a cross between two varieties of Triticum vulgare, 631–658; to P. sorghi in maize, 138
Inhibition of enzymatic action as a possible factor in the resistance of plants to disease, 953
Injury, leaf-hopper, to legumes, 137–138
In memoriam, 475
Inoculum, quantity of, in relation to severity of stem-rust epidemics, 81–83
Insects, carriers of tip and margin burn of Irish potatoes, 141; technique for feeding, 246–247
Intracellular bodies, occurrence of, in spike disease of sandal and Vinca, 815–817
Investigations of Aspergilli by serological methods, 148
Iris versicolor, susceptibility to Bacillus carotovorus, B. phytophthorus, and B. aroideae, 833–835
Irrigation as a cause of white spot of alfalfa, 136–137
Isolation of single spores, apparatus for, 1017–1021; method of, 17–19

JAGGER, IVAN C., The brown-blight disease of lettuce, 949–950
Jasminum primulinum, 952
JEHLE, R. A., and H. A. HUNTER, Observations on the discharge of ascospores of Venturia inaequalis in Maryland, 943–945
JOHANN, HELEN, Grated carrot agar favorable for studies of Pythium, 710; Penicillium injury to corn seedlings, 239–242
JOHNSON, E. M., see VALLEAU, W. D.
JOHNSON, H. W., see PETERSON, P. D.
JOHNSON, JAMES, Constant-temperature and humidity chambers, 227–238; Further studies on the attenuation of plant viruses, 156; The properties and behavior of potato rugose mosaic, 141
JOHNSON, T., The occurrence of yellow stripe rust in western Canada, 481; see NEWTON, M.
JONES, J. P., The influence of cropping systems and fertilizers on black and brown root rot of tobacco, 131
JONES, L. R., and REGINA S. RIKER, Studies upon the Fusarium wilt of China aster, 150
Juglans, californica, 948–949; cinerea, lesions produced by Gnomonia leptostyla, 746; hindsii, 948–949

KEITT, G. W., and E. E. WILSON, Fall applications of fungicides in relation to apple-scab control, 146; see BENSAUDE, M.; see HAMILTON, J. M.; see RIKER, A. J.
KLOTZ, L. J., Inhibition of enzymatic action as a possible factor in the resistance of plants to disease, 953
Knots, callus, on apple, grafting as a further means of preventing, 127–128
Knotweed, Uromyces polygoni on, experimental control of teliospore and uredinospore formation, 178–179, 206
KOHL, EDWIN J., The cycle of infection in apple blotch, 145
Krankheiten, Die, der Obstbäume und Obststräucher, by E. EWERT, book review, 715
KUNKEL, L. O., Further studies on the host range of aster yellows, 156

LACKEY, C. F., see CARSNER, EUBANKS
LEE, H. ATHERTON, and W. DWIGHT PIERCE, Bacterial red-stripe disease of sugar cane in countries of the Pacific, 945
LAMBERT, E. B., see E. C. STAKMAN
Lathyrus odoratus, susceptibility to Erostrotheca multiformis, 839–844
LEACH, L. D., see S. M. DIETZ
Leaf-hopper injury of legumes, 137–138
Leaf hoppers, transmission of sugar-beet curly top by, 675–679, 681–690
Leaf spot, angular, and fruit rot of cucumber, 133; ascomycetous, of cowpea, 701–704; new, of pecan, preliminary report on, 133–134
Leaf-spotting fungi, histologic changes induced in leaves, 717–751
Leaves, histologic changes induced in, by leaf-spotting fungi, 717–751
LEE, H. ATHERTON, and J. P. MARTIN, Oxidizing agents in sulphur to increase fungicidal activity, 1026–1027; and J. S. MCHARGUE, The effect of a manganese deficiency on the sugar-cane plant and its relationship to Pahala blight of sugar cane, 775–786
Legumes, leaf-hopper injury to, 137–138
LEPIK, E., Differential staining of Peronosporaceae, 869–872
Leptosphaerulina vignae, n. sp., cause of leaf spot of cowpea, 701–704
Lesions, cicatrice definitely formed about margin of, 723–731; cicatrice not definitely formed about edge of, 731–747
Leskaceae, 952
Lettuce, brown blight of, 949–950
Leucolepis acanthoneura, 952
LEVINE, MICHAEL, Studies on crown-gall transplants, 130
LEVINE, MOSES N., Biometrical studies on the variation of physiologic forms of Puccinia graminis tritici and the effects of ecological factors on the susceptibility of wheat varieties, 7–123
Light, monochromatic, photography in the study of mosaic diseases, 154; relation to experimental control of teliospore and urediniospore formation, 163–180, 206–207
Lilium auratum, mechanical transmission of mosaic of, 1025–1026
Lime, effects of, on cigar tobacco, 130–131; sulphur, fungicidal action, 355–360
Linum, reaction to rust and powdery mildew, 478
Locustidae, transmission of potato spindle tuber by, 445–448; transmitting potato spindle tuber, 140
Longevity of Pseudomonas tumefaciens Sm. & Town. in various soils, 129
Losses, determination of, in selfed lines of smutted corn, 599–602
Lycopersicum esculentum, lesions produced by Alternaria solani, 740

MACKIE, J. R., Localization of resistance to powdery mildew in the barley plant, 901–910
MACKIE, W. W., A field method of insuring positive attack with some cereal diseases, 617–621; Inheritance of resistance to blast in oats, 948
Macrosporium cucumerinum, lesions produced on Cucumis melo, 740–741
Maggot, seed-corn, transmission of potato black leg by Hylemyia cilicrura in Maine, 459
MAINS, E. B., Inheritance of resistance to Puccinia sorghi in maize, 138; and DOROTHY THOMPSON, Studies on snapdragon rust, Puccinia antirrhini, 150
Maize, inheritance of resistance in, to Puccinia sorghi, 138; root rot caused Pythium arrehomanes, 873–875; see corn
MAJOR, T. G., see SLAGG, C. M.
Manganese deficiency, relationship to Pahala blight of sugar cane, 775–786
Manihot esculenta, mosaic of, in West Africa, 155
MARCHAL, E., First report of the occurrence of Black scab or warty disease of potato in Belgium, 126
Margin, burn, of Irish potatoes, relationship of insect carriers to development of, 141
MARLOTH, R. H., see DAVIS, A. R.
MARTIN, G. HAMILTON, and VERA K. CHARLES, Preliminary studies of the life

history of Erostrotheca multiformis, the perfect stage of Cladosporium album Dowson, 839–846

MARTIN, J. P., see LEE, H. ATHERTON

MASSEY, L. M., Dry rot of Gladiolus corms, 519–529

MATSUMOTO, TAKASHI, Preliminary note on some serological studies of Aspergilli, 691–696; Some investigations of Aspergilli by serological methods, 148

MCCUBBIN, W. A., Permanent mounts of white-pine-blister-rust aecia, 1029

MCCULLOCH, LUCIA, and CHARLES THOM, A corm rot of Gladiolus caused by a Penicillium, 151; **Bacterium maculicola** (McC.), nom. emend. syn. Bact. maculicolum, 460; **Bact. stizolobii** (Wolf), comb. nov. syn. Aplanobacter stizolobii, 460

MCHARGUE, J. S., and LEE, H. ATHERTON

MCKINNEY, H. H., Virus diseases observed by the Allison V. Armour Expedition, 155 Measurements of total sunlight intensity with reference to the ecology of plant diseases, 951

Mechanical transmission of mosaic of Lilium auratum, 1025–1026

Medicago lupulina, lesions produced by Pseudopeziza medicaginis, 752; sativa, lesions produced by Pseudopeziza medicaginis, 741–742

Melampsora humboldtiana, on Salix species, 705–708; lini, reaction of Linum species to, 478

Melampsorella elatina, on Cerastium and Stellaria species, 705–708

MELHUS, I. E., and D. R. PORTER, The use of selection and selfing in improving Iacope cabbage, 142; J. H. MUNCIE, and VERNON C. FISK, Grafting as a further means of preventing callus knots on apple, 127–128

Menispermum canadense, lesions produced by Cercospora menispermi, 736–737

Mercuric, chloride and cyanide, in fire-blight-eradication work, 710–711; cyanide and chloride, in fire-blight-eradication work, 710–711

Mercury as a control for turf diseases, 137

Method, field, of epidemic induction of cereal disease, 617–621; of measuring the relative efficiency of seed-corn disinfectants, 140

Methods, for eradicating species of Rhamnus, 138; isolation of single spores, 17–19; permanent mounts of white-pine-blister-rust aecia, 1029; serological, investigations of Aspergilli by, 148; spore measurements, 19–20; technique for feeding homopterous insects, 246–247; uniform wheat rust nurseries, 13–17

Methyl violet for staining Bacillus tracheiphilus, 803–807

Microsphaera alni, 904

Migration of Bacterium tumefaciens, in tomato, 129; in tomato tissue, 553–564

Mildew, powdery, control of, 847–860; powdery, in barley plant, 901–910; powdery, of raspberry, 787–796; powdery, parasitizing Chinese cabbage, 611–615

Milesia, kriegerina, on Dryopteris spinulosa, 705–708; marginalis, on D. marginalis, 705–708; polystichi, on polystichum munitum, 705–708; pycnograndis, on Polypodium vulgare, 705–708

Millet, control of smut, 479

Mniaceae, 952

Moisture, relation to development of ascigerous stage of Venturia inaequalis, 409–414; relation to experimental control of teliospore and urediniospore formation, 181–184, 207–208; soil, effect of, on mycorrhizae, 257; soil, effect of, on sugar-beet root rot, 273–275

Monochromatic-light photography in the study of mosaic diseases, 154

MONTEITH, JOHN, JR., Leaf-hopper injury of legumes, 137–138; and A. S. DAHL, Mercury as a control for turf diseases, 137

MONTREUIL, J. E., see SLAGG, C. M.

Morphological and other characters in relation to stem-rust resistance in mature wheat plants, 650–656

Morphology (morphometry) of some important physiologic forms of Puccinia graminis tritici, 40–81; of Cladosporium strains, 324–325

Mosaic, and streak, of tomato, soil transmission of, 155; cucumber, resistance of Chinese cucumber to, 143; cytological

studies of plant tissues affected with, 154; disease of Gladiolus, 215–217; diseases, studied with monochromatic light, 154; effects upon chlorophyll content of tobacco, 697–700; of bean, transmission of, 155; of cucumber, transmitted by aphis, 143; of Lilium auratum, mechanical transmission of, 1025–1028; potato rugose, properties and behavior of, 141; tobacco, true, experiments and observations on the control of, 132; virus, a "streak" of tomatoes produced by disturbing principle from healthy potatoes in combination with, 311; virus, of tobacco, accuracy in comparing various concentrations of, 132

Moss, E. M., The haustorium of Cuscuta gronovii, 478

Mottle-leaf disease of beech, 151–152

Mounts, permanent, of white-pine-blister-rust aecia, 1029

Muncie, J. H., Rumex crispus, a weed host of Pseudomonos tumefaciens, 130; see Melhus, I. E.; and W. B. Shippy, Overgrowths and hairy root on nursery-apple and quince trees, 127

Mycorrhizae, sugar-cane, and their relation to root diseases, 249–261

Mycorrhizal fungus of Vaccinium, 148

Mycosphaerella, fragariae, lesions produced on Fragaria virginiana, 774; grossulariae, lesions produced on Ribes prostratum, 744–745; sentina, lesions produced on Pyrus communis, 727

Narasimhan, M. J., Note on the occurrence of intracellular bodies in spike disease of sandal (Santalum album Linn.), 815–817

Neal, D. C., Outstanding wilt-resistant-cotton varieties, 134

Neatby, K. W., see Goulden, C. H.

Needle rusts on balsam firs in North America, conspectus of, 705–708

Nematodes, cause of root knot of abacá, 861–867

Nemopanthus mucronata, lesions produced by Rhytisma ilices-canadensis, 743–744

Newton, George A., Some fungi of the Stemphylium type and their relation to apple rots, 565–578

Newton, M., see Brown, A. M.; see Johnson, T.; T. Johnson, and A. M. Brown, Physiologic forms of wheat stem rust in Canada, 478–479

Nicotiana glauca, mosaic of, on Canary Islands, 155

Nisikado, Y., Review of Shirai and Hara's book, A list of Japanese fungi hitherto unknown, 1023

Notes, phytopathological, 125–126, 245–248, 311–312, 459–461, 1025–1030; Ericksson prizes, 1029–1030; field meeting, Southern Section, American Phytopathological Society, 460–461.

Nuckols, S. B., and Tompkins, C. M.

Nurseries, uniform wheat-rust, 13–17, 20–31

Nursery trees, apple and quince, overgrowths and hairy root on, 126

Nutrients, soil, effect on mycorrhizae, 257–258

Oat, blast, 948; dust treatment for smuts of, 139

Oats, Fusarium blight of, 480; physiologic forms of stem rust in Canada, 479–480; varietal resistance to Ustilago levis and U. avenae, 993–997

Observations on the discharge of ascospores of Venturia inaequalis in Maryland, 943–945

Obstbäume und Obststräucher, Die Krankheiten der, book review, 715

Occurrence, of intracellular bodies in spike disease of sandal (Santalum album), 815–817; of Peronospora sparsa Berk. on hothouse roses in southern California, 950; of pycnia and aecia in certain rust fungi, 1005–1015

Ocfemia, Gerardo Offimaria, and Melanio R. Calinisan, The root knot of abacá, or Manila hemp, 861–867

O'Gara, Patrick Joseph, In memoriam, 475

Ogilvie, Lawrence, "Black tip," a finger-tip disease of the Chinese banana in Bermuda, 531–538

Oidium sp., relation of Linum species to, 478

Oleander bacteriosis, 503–518

O'Leary, Keith, Eocronartium musicola

fr. in a new locality and on a new host, 952
Olives, copper sulphate as remedy for exanthema in, 449–454
Onoclea sensibilis, host of Uredinopsis mirabilis, 705–708
Oospora citri-aurantii, 949
Ophiobolus graminis Sacc., the reaction of wheat varieties to inoculations with, 477
Origin of Phytophthora infestans, 494–500
Ornamental plants, condition of bulbs and corms of, offered for importation into Canada, 150–151
ORTON, C. R., The effect of disinfectants upon the germination of seeds kept in storage for indefinite periods after treatment, 136
Osmorhiza longistylis, lesions produced by Septoria osmorhizae, 734–735
Osmunda species, hosts of Uredinopsis osmundae, 705–708
Overgrowth, wound, correlation of, and crown gall of apple, 128
Overgrowths, and hairy root on nursery-apple and quince trees, 127; wound, studies of the history of development of, and of the influence of wrappers on their suppression, 128
Oxidizing agents in sulphur to increase fungicidal activity, 1026–1027

Pahala blight of sugar cane, effect of manganese deficiency on, 775–786
Palm, Washingtonia, leaf spot due to Cylindrocladium macrosporum, 219–225
PÄMMEL, L. H., Cladosporium diseases, 946
Paragynous antheridia of Phytophthora spp., 149–150
Parasitism, (host plants, host range, pathogenicity), tobacco ring spot, 133; host range of aster yellows, 156; of Aphanomyces euteiches on conifers, 366; of Bacilus spp. to potato tubers, 819–838; of Corticium koleroga, 147–148; of physiologic forms of cereal smuts, 981–997; of physiologic forms of Tilletia levis and T. tritici, 985–992; of physiologic forms of Ustilago hordei, 992–993; of Pythium spp. on conifers, 363–366; relation of variety of apple to production of ascigerous stage of Venturia inaequalis, 393–395
Paratrioza cockerelli, its relation to a new potato disease in Utah, 140–141
PATEL, M. K., Longevity of Pseudomonas tumefaciens Sm. & Town. in various soils, 129; Strains of Ps. tumefaciens Sm. & Town. and their prevalence in various soils, 129–130; A study of pathogenic and nonpathogenic strains of tumefaciens Sm. & Town., 331–343
Pathogenicity, of Fusarium vasinfectum, 419–438; of Sclerotium gladioli, 524
PATTERSON, FLORA W., 877–879
Peach scab, caused by Cladosporium, 313
Pears, copper sulphate as remedy for exanthema in, 499–454
Pecan, preliminary report of a new leaf spot of, 133–134
Pelargonium zonale, susceptibility to Bacillus carotovorus, B. aroideae, and B. phytophthorus, 834–835
PELTIER, GEORGE L., Control of bunt of wheat in Nebraska, 921–929
Penetration, mode of, by Cladosporium carpophilum, 316–318; of furfural in plant tissues, 152
Penicillium, causing a corm rot of Gladiolus, 151; corm rot of Gladioli, 151; digitatum, 949; Gladioli, corm rot of Gladioli, 151; injury to corn seedlings, 239–242; italicum, 949; oxalicum, possible cause of injury to corn seedlings, 239–242
Pentstemon, rust on, 665
Peony, the crown-elongation disease of, 243–244; Phytophthora blight of, 881–900
Peridermium, balsameum, on Abies species, 705–708; columnare, on Abies species, 705–708; elatinum, on Abies species, 705–708; kriegerina, on Abies balsamea, 705–108; marginalis, on Abies balsamea, 705–108; ornamentale, on Abies species, 705–708; pustulatum, on Abies species, 705–708, pycnoconspicuum, on Abies balsamea, 705–708; pycnogrande, on Abies balsamea, 705–708; rugosum, on Abies species, 705–708; sp., possible

aecial stage of Pucciniastrum myrtilli, 623–625
Peritheeia of Venturia inaequalis, factors important in development of, 145–146
Permanent mounts of white-pine-blister-rust aecia, 1029
Peronospora sparsa, 950
Peronosporaceae, differential staining of, 869–872
PETERSON, P. D., and H. W. JOHNSON, Powdery mildew of raspberry, 787–796
Petri-dish experiments for control of teliospore and urediniospore formation, 184–199
Phaseolus vulgaris, Uromyces appendiculatus on, experimental control of teliospore and urediniospore formation, 163–169, 183, 184–187, 206
Phegopteris dryopteris, host of Hyalospora aspidiotus, 705–708; host of Uredinopsis phegopteridis, 705–708
Phoma, 917; betae, 941; sp., 952
Phomopsis, californica, 949; sp., causing cranberry storage rot, 809–814
Photographic collection of ERWIN F. SMITH, 312
Photography, monochromatic-light, in the study of mosaic diseases, 154
Phyllosticta fraxinii, lesions produced on Fraxinus americana, 741
Phymatotrichum (Ozonium) omnivorum, 952–953
Physiologic specialization, biometrical studies of physiologic forms of Puccinia graminis tritici, 40–81; cultural differences between physiologic forms of cereal smuts, 958–972; effect of temperature on growth of physiologic forms of cereal smuts, 972–981; forms of P. graminis avenae in Canada, 479–480; forms of wheat stem rust in Canada, 478–479; in P. sorghi, 349–352; in some cereal smuts, 955–1003; new forms of Tilletia levis and T. tritici, 579–588; new physiologic forms of T. tritici in wheat, 139; pathogenic differences between physiologic forms of cereal smuts, 981–997; stability of physiologic forms of P. graminis tritici under diverse cultural conditions, 108–113; strains of Cladosporium affecting stone fruits, 318–322, 327–328; strains of Pseudomonas tumefaciens, 129–130; two forms of Ustilago striaeformis (Westd.) Neissl., 149
Phytomonas malvacera, 951
Phytopathological Society, see American Phytopathological Society
Phytophthora, 881–882, 884–886, 890–895, 897; blight, 881–882, 896–897; cactorum, 881, 884, 889, 894–896, 898, 948–949; colocasiae, 894; cryptogea, 894; erythroseptica, 893–895, 898; faberi, 895; fagi, 881, 894–895; in relation to crown rot of walnut, 948–949; infestans, 894–895; infestans, origin of, 494–500; jatrophae, 895; mexicana, 894; nicotianae, 889–890, 895; omnivora, 895; paeoniae, 881, 896–899; palmivora, 894; parasitica, 894–895; phaseoli, 895; pipi, 894; richardiae, 895; rot of apple, 885; rot of ginseng, 885; rot of strawberry, 885; species as stock cultures, 247–248; spp., paragynous antheridia of, 149–150; syringae, 895; terrestris, 894–895
PIERCE, W. DWIGHT, see LEE, H. ATHERTON
Pima cotton, 951
Pine, white, permanent mounts of blister-rust aecia of, 1029
Pink rot, 931
PITTMAN, D. W., see STEWART, GEORGE
PLAKIDAS, A. G., Strawberry dwarf, 439–444
Plants, disease-resistant, cytological phenomena in, 144
Plasmodiophora, brassicae, in relation to soil alkalinity, 301–306; reaction and treatment of soils infested with, 141–142
Plasmopara viticola, differential staining of, 869–872
Pleospora mali, n. sp., cause of apple rot, 576
Plum, scab caused by Cladosporium, 313–314
PLUNKETT, O. A., The occurrence of Peronospora sparsa Berk. on hothouse roses in southern California, 950
Podophyllum peltatum, lesions produced by Septoria podophyllina, 731–732
Polygala senega, rust on, 665

Polygonum aviculare, Uromyces polygoni on, experimental control of teliospore and urediniospore formation, 178–179, 206
Polypodium vulgare, host of Milesia pycnograndis, 705–708
Polystichum munitum, host of Milesia polystichi, 705–708
POOLE, R. F., Sweet-potato stem rot prevented by treating stems and roots with Bordeaux mixture, 152–153
Populus sp., 952
PORTER, C. L., see COOPER, D. C.
PORTER, D. R., see MELHUS, I. E.; Studies with the watermelon wilt, caused by Fusarium niveum E. F. Sm., 143–144; Varietal resistance of watermelon to wilt (Fusarium niveum E. F. Sm.), 144
PORTER, R. H., Further evidence of resistance to cucumber mosaic in the Chinese cucumber, 143; Seed disinfectants for the control of covered smut and stripe of hulless barley, 139; T. F. YU and H. K. CHEN, The effect of seed disinfectants on smut and yield of millet, 911–919
Potato, a new and destructive disease of, in Utah, 140–141; black scab or warty disease of, in Belgium, 126; Irish, relationship of insect carriers to development of tip and margin burn of, 141; pathogenicity of Bacillus mesentericus, B. aroideae, B. carotovorus, and B. phytophthorus to, 819–832; psylla of, its relation to a new potato disease in Utah, 140–141; rugose mosaic of, properties and behavior of, 141; transmission of black leg by seed-corn maggot, 459; transmission of spindle tuber by grasshoppers, 445–448; transmission of spindle tuber of, 140
Potatoes, blight-resistant, 483–502; varietal susceptibility of, to Fusarium wilt and stem-end rot, 307–309
Powdery mildew, and rust, reaction of Linum species to, 478; control of, 847–860; of raspberry, 787–796
Pox, or soil rot, in sweet potato, caused by an Actinomycete, 152
Predisposition, condition of host plants to severity of stem-rust epidemics, 83–90; of sugar beets to late root rot, 263–276
Preliminary note on some serological studies of Aspergilli, 691–696
Prenanthes alba, Puccinia orbicula on, experimental control of teliospore and urediniospore formation, 197–199
Primula polyantha, lesions produced by Ramularia primulae, 738
Prize offered by the State of Rio de Janeiro, Brazil, 713
Prizes, Eriksson, announcement of, 1029–1030
Production of agglutinins by phytopathogenic bacteria, 277–288
Progress of rust studies, 659–674
Properties and behavior of potato rugose mosaic, 141
Prunes, copper sulphate as remedy for exanthema in, 449–454
Prunus, armeniaca, 952; avium, lesions produced by Coccomyces hiemalis, 727; cerasus, lesions produced by C. hiemalis, 726–727; domestica, lesions produced by C. prunophorae, 723–725; serotina, lesions produced by Cercospora circumcissa, 737–738; virginiana, lesions produced by Coccomyces lutescens, 725–726
Pseudomonas, cerasus, production of antisera against, 278–288; savastanoi var. nerii, cultural characteristics, 513–515; savastanoi var. nerii, host relationship, 512–513; tumefaciens, a study of pathogenic and nonpathogenic strains, 331–343; tumefaciens, on Rumex crispus, a weed host of, 130; tumefaciens, see Bacterium tumefaciens; tumefaciens Sm. & Town, longevity of, in various soils, 129; tumefaciens Sm. & Town., strains of, and their prevalence in various soils, 129–130
Pseudopeziza, medicaginis, lesions produced on Medicago lupulina, 472; medicaginis, lesions produced on M. sativa, 741–742; ribis, lesions produced on Ribes grossularia, 742–743; trifolii, lesions produced on Trifolium pratense, 742
Psoralea bituminosa, mosaic of, on Canary Islands, 155
Psylla, potato, its relation to a new potato disease in Utah, 140
Pteridium aquilinum and P. pubescens,

hosts of Uredinopsis macrosperma, 705–708

Puccinia, andropogonis, 665; anomala, in western Canada, 481; anomala, method of epidemic induction, 617–621; antirrhini on Antirrhinum majus, experimental control of teliospore and urediniospore formation, 176–178, 183–184, 192–194; antirrhini, rust of snapdragon, 150; asparagi on Asparagus officinale, experimental control of teliospore and urediniospore formation, 180, 181–183; comandrae, 665; coronata, heterothallism in, 1005–1015; coronata, method of epidemic induction, 617–621; coronata, on species of Rhamnus, 138; glumarum, in western Canada, 481; graminis avenae, physiologic forms in Canada, 479–480; graminis, heterothallism in, 147, 1005–1015; graminis, method of epidemic induction, 617–621; graminis, rust epidemic induction, 617–621; graminis, rust epidemics and temperature, 372–374; graminis, sexual behavior of, 479; graminis tritici, biometrical studies on the variation of physiologic forms of, and the effects of ecological factors on the susceptibility of wheat varieties to, 7–123; graminis tritici, consistency in behavior of different strains of identical forms of, 112–113; graminis tritici, field observations on severity of epidemics, 20–31; graminis tritici, greenhouse and laboratory studies of physiologic forms of, 31–81; graminis tritici, identity and nature of physiologic forms isolated from uniform rust nurseries in 1919–1923, 33–35; graminis tritici, inheritance of resistance to, in a cross between two varieties of Triticum vulgare, 631–658; graminis tritici, inoculation technique and cultural methods in greenhouse, 17–20; graminis tritici, morphology of some important physiologic forms of, 40–81; graminis tritici, physiologic forms in Canada, 478–479; graminis tritici, prevalence and distribution of physiologic forms isolated from uniform rust nurseries in 1919–1923, 35–40; graminis tritici, single-spore isolations and spore measurements of, 17–20; graminis tritici, stability of physiologic forms under diverse cultural conditions, 108–113; graminis tritici, uniform rust nurseries, 13–17, 20–31; graminis tritici, uniformity of behavior over long periods of time of different physiologic forms of, 108–112; helianthi, heterothallism in, 147, 1005–1015; orbicula on Prenanthes alba, experimental control of teliospore and urediniospore formation, 197–199; pentstemonis, 665; podophylli, 671; pringsheimiana, heterothallism in, 1005–1015; rubigo-vera, 666–667; seymeriae, 665; sorghi, inheritance of resistance to, in maize, 138; sorghi, on Zea mays, experimental control of teliospore and urediniospore formation, 179–180, 194–195, 206; sorghi, physiologic specialization, 345–354; suaveolens on Cirsium arvense, experimental control of teliospore and urediniospore formation, 169–172, 191–192, 206; taraxaci on Taraxacum officinale, experimental control of teliospore and urediniospore formation, 175–176, 196–197; triticina, method of epidemic induction, 617–621; triticina on Triticum vulgare, experimental control of teliospore and urediniospore formation, 179, 195–196

Pucciniastrum, abietichamaenerii, on Epilobium species, 705–708; epilobii, on Epilobium species, 705–708; myrtilli, on Vaccinium species, 705–708; myrtilli, possible alternate stage of, 623–625

Pycnia, occurrence of, in certain rust fungi, 1005–1015; occurrence under natural conditions, unaccompanied by aecia, 1010–1014

Pyrus communis, lesions produced by Mycosphaerella sentina, 727

Pythiacystis, 953; citrophthora, 949; species as stock cultures, 247–248

Pythium, arrhenomanes, cause of maize root rot, 873–875; arrhenomanes, comparison with P. aphanidermatum, 874; grated-carrot agar for, 710; species as stock cultures, 247–248; spp., pathogenicity for conifers, 363–366

QUANJER, H. M., book review, Die Krankheiten der Obstbäume und Obststräucher,

by E. EWERT, 715; Eriksson prizes, 1029–1030
Quercus pedunculata, 904
Quince, and apple, nursery trees, overgrowths and hairy root on, 127

RALEIGH, W. P., A preliminary method of measuring the relative efficiency of seed-corn dinifectants, 140
Ramularia, **carniformis** (E. & T.), n. com. on Tripsacum dactyloides, 149; decipiens, lesions produced on Rumex crispus, 739; primulae, lesions produced on Primula polyantha, 738; ranunculi, lesions produced on Ranunculus recurvatus, 738–739
RANKIN, W. HOWARD, Mottle-leaf disease of beech, 151–152
Ranunculus recurvatus, lesions produced by Ramularia ranunculi, 738–739
Raspberry, powdery mildew, 787–796
Reaction and treatment of soils infested with Plasmodiophora brassicae Wor., 141–142
Red stripe, bacterial, disease of sugar cane, 945
REDDICK, DONALD, Blight-resistant potatoes, 483–502
Relationship of insect carriers to the development of tip and margin burn of Irish potatoes, 141
Report, of nineteenth annual meeting of American Phytopathological Society, 463–474; of ninth annual meeting of Canadian Division of American Phytopathological Society, 477–481; of progress, on condition of bulbs and corms of ornamental plants offered for importation into Canada, 150–151; on a new leaf spot of pecan, 133–134; on insect carriers of tip and margin burn of Irish potatoes, 141; on mechanical transmission of mosaic of Lilium auratum, 1025–1026
Resistance, cytological phenomena in disease-resistant plants, 144; Ekishirazu, blight-resistant variety of potato, 484; inheritance of, to Puccinia sorghi in maize, 138; of host, relation to teliospore formation, 208–209; of varieties of watermelons to wilt (Fusarium niveum), 144; relative, of selfed lines of corn to rust, 345–349; see susceptibility; to cucumber mosaic in Chinese cucumber, 143; to Puccinia graminis tritici, inheritance of, in a cross between two varieties of Triticum vulgare, 631–658; to stem rust in mature plants in relation to morphological and other characters, 650–656; varietal, of cereal crops to physiologic forms of smut, 981–997
Review, of A list of Japanese fungi hitherto unknown, 1023; of Plantsiektes hul oorsaak destryding, 1023
Rhabdospora oxydendri, (E. & E.), n. com. on Oxydendrum arboreum, 149
Rhamnus, effective methods for eradicating species of, susceptible to Puccinia coronata, 138
Rhynchosporium secalis, method of epidemic induction, 617–621
Rhytisma, acerinum, lesions produced on Acer rubrum, 744; ilices-canadensis, lesions produced on Ilex verticillata, 743; ilices-canadensis, lesions produced on Nemopanthus mucronata, 743–744
Ribes, grossularia, lesions produced by Pseudopeziza ribis, 742–743; prostratum, lesions produced by Mycosphaerella grossulariae, 744–745
RICHARDS, B. L., A new and destructive disease of the potato in Utah and its relation to the potato psylla, 140–141; Irrigation as a cause of white spot of alfalfa, 136–137
RIKER, A. J., A bacterial disease of broad beans, 136; Correlation of the wound overgrowth and crown gall of apple in parts of Europe and of the United States, 128; Noes on crown gall situa- in England, France and Holland, 289–294; W. M. BANFIELD and G. W. KEITT, Studies of the history of development of wound overgrowths on apple grafts and of the influence of wrappers on their suppression, 128
RIKER, REGINA S., see JONES, L. R.
Ring spot of tobacco, a virus disease with a wide host range, 133
RODENHISER, H. A., Experiments on the control of barley stripe, 295–300; Physio-

logic specialization in some cereal smuts, 955–1003

Root, and crown injury, apple trees, 547–551; club, in relation to soil alkalinity, 301–306; diseases, observations on sugar-cane mycorrhizae and their relation to, 249–261; diseases, prevention of sugar cane, 259; knot, of abacá, 861–867; knot, symptoms on abacá, 861–863; rot, black and brown, of tobacco, influence of cropping systems and fertilizers on, 131; rot, black, of apple, 145; rot, black, of tobacco and soil reaction, 131; rot, brown, of tobacco, effect of timothy infusions on, 131–132; rot, late, predisposition of sugar beets to, 263–276; rot, Texas, 952–953

Rosen, H. R., A consideration of the pathogenicity of the cotton-wilt fungus, Fusarium vasinfectum, 419–438; A preliminary report on the relationship of insect carriers to the development of tip and margin burn of Irish potatoes, 141

Roses, occurrence of Peronospora sparsa Berk. on, 950

Rot, black, of sweet potatoes, treatment for control of, 153–154; corm, of Gladiolus, caused by a Penicillium, 151; dry, of Gladiolus corms, 519–529; in sweet potato, caused by an Actinomycete, 152; Penicillium, corm, of Gladioli, 151; root, caused by Pythium arrhenomanes, 873–875; stem-end, varietal susceptibility of potatoes to Fusarium wilt and, 307–309

Rots, apple, relation of Stemphylium type of fungi to, 565–578; storage, of cranberries, in 1927, 809–814

Rumex crispus, lesions produced by Ramularia decipiens, 739; a weed host of Pseudomonas tumefaciens, 130

Russell, R. C., The reaction of wheat varieties to inoculations with Ophiobolus graminis Sacc., 477

Rust, and powdery mildew, reaction of Linum species to, 478; blister, of white pine, permanent mounts of aecia of, 1029; epidemics, wheat stem, 369–374; fungi, heterothallism in, 147; fungi, occurrence of pycnia and aecia in, 1005–1015; fungi, teliospore and urediniospore formation controlled experimentally, 157–213; inheritance of resistance in mature plants in relation to morphological and other characters, 650–656; leaf and stem, sulphur dusting for control of, 480; leaf, dwarf, on barley in western Canada, 481; of corn, Puccinia sorghi, 345–354; of snapdragon, P. antirrhini, 150; of wheat, effect of ecological factors on susceptibility of varieties to, 81–108; stem, inheritance of resistance to, in wheat, 631–658; stem, of wheat, see P. graminis tritici; stem, physiologic forms of, on oats, in Canada, 479–480; stem, physiologic forms of, on wheat, in Canada, 478–479; stripe, occurrence in western Canada, 481; studies, progress of, 659–674

Rusts, needle, on balsam firs in North America, conspectus of, 705–708; of the Pacific Northwest, 948

Salix species, alternate hosts of fir-needle rust, 705–708

Sandal, occurrence of intracellular bodies in spike diesease of, 815–817

Sanford, G. B., Cereal diseases in Alberta in 1927, 481

Santalum album, occurrence of intracellular bodies in spike disease of, 815–817

Savastano, G., and H. S. Fawcett, The effect of mixed inoculations of certain citrus fruit-rotting organisms, 949

Sayre, J. D., and R. C. Thomas, New dust treatments for oat smuts, 139

Scab, apple, see Venturia inaequalis; black, or warty disease of potato, in Belgium, 126; of apple, certain sulphur fungicides in control of, 146–147; of apple, fall applications of fungicides in relation to control of, 146

Scandiffio, Mario, see Church, Margaret B.

Scheffer, T. C., Steam sterilization of coniferous seed beds, 952

Sclerospora graminicola, 917

Sclerotinia libertiana, 949

Sclerotium gladioli, n. sp., etiology of dry rot of Gladiolus, 521–524, pathogenicity.

524, cultural characters, 524–526, life history, 526–527, control, 527–528
Seed, cotton, treatment by the dusting method, 134; disinfectants, effect on smut and yield of millet, 911–919; disinfectants for control of covered smut and stripe of hulless barley, 139; effect of washing on infection of wheat by stinking smut, 711–713
Seedling blight, on oats, caused by Fusarium culmorum, 480
Seeds, effect of disinfectants upon germination of, in storage, 136
Selection and selfing for improving Iacope cabbage, 142
Selfing for improving Iacope cabbage, 142
Septoria, acerina, lesions produced on Acer pennsylvanicum, 734; cirsii, lesions produced on Cirsium arvense, 733; conspicua, lesions produced on Steironema ciliatum, 732–733; of tomato, control by means of forced ventilation in hotbeds, 1027–1029; osmorhizae, lesions produced on Osmorhiza longistylis, 734–735; petroselini, lesions produced on Apium graveolens, 731; podophyllina, lesions produced on Podophyllum peltatum, 731–732; tritici, method of epidemic induction, 617–621; verbasicola, lesions produced on Verbascum blattaria, 733–734
Serological, investigations of Aspergilli, 148; studies on Aspergilli, 691–696
Setaria italica, 911
SEVERIN, HENRY H. P., Tomato yellows or tomato curly top, 709–710; and OLIVE SWEZY, Filtration experiments on curly top of sugar beets, 681–690
Sex in Puccinia graminis, 479
SHAPOVALOV, MICHAEL, and F. S. BEECHER, The development of tomato yellows under light conditions, 950
SHERBAKOFF, C. D., An examination of Fusaria in the herbarium of the Pathological Collections, Bureau of Plant Industry, U. S. Department of Agriculture, 148–149; Washingtonia palm-leaf spot due to **Cylindrocladium macrosporum**, n. sp., 219–225
SHIPPY, W. B., see MUNCIE, J. H.
SHIRAI, M., and K. HARA, A list of Japanese fungi hitherto unknown, review of, 1023
SIMMONDS, P. M., A seedling-blight disease of oats caused by Fusarium culmorum, 480
Single spores, see spores, single
SKORIC, VLADIMIR, see WRIGHT, WILLIAM H.
SLAGG, C. M., J. E. MONTREUIL, and T. G. MAJOR, The effects of lime on cigar tobacco, 130–131
SMITH, CLAYTON O., Oleander bacteriosis in California, 503–518; A study of citrus blast and some allied organisms, 952
SMITH, ERWIN FRINK, In memoriam, 475; Photographic collection of, 312; Testimonial to, 1–5
SMITH, RALPH E., and HAROLD E. THOMAS, Copper sulphate as a remedy for exanthema in prunes, apples, pears, and olives, 449–454
Smut, covered, of hulless barley, control of, 139; influence of environmental factors on prevalence in corn, 589–598; losses in selfed lines of corn, 599–602; oat, dust treatments for, 139; of millet, 911–919; stinking, of wheat, effect of washing seed on infection, 711–713; treatment of millet seed for prevention of, 479
Smuts, cereal, physiologic specialization in, 955–1003
Snapdragon, Puccinia antirrhini on, experimental control of teliospore and urediniospore formation, 176–178, 183–184, 192–194; rust of, antirrhini, 150
Snowberry, anthracnose of, 797–801
Soft rot, 931
Soil, alkalinity in relation to clubroot, 301–306; in relation to severity of stem-rust epidemics, 90–91; productivity, effect of, on sugar-beet root rot, 268–272; reaction, and black root rot of tobacco, 131; transmission of tomato mosaic and streak in the greenhouse, 155
Soils, longevity of Pseudomonas tumefaciens Sm. & Town. in, 129; prevalence of strains of Ps. tumefaciens in, 129–130

Solanum tuberosum, lesions produced by Alternaria solani, 739–740
Solutions, sugar, for experimental control of teliospore and urediniospore formation, 184–199; transmission of virus of curly top of sugar beet through, 675–679
Sonchus oleraceus, 904
SØRENSEN, S. P. L., Emil Chr. Hansen Medal, 1928, 125
SPALTEHOLZ, R., Review of van der Bijl's book, Plantsiektes hul oorsaak en bestryding, 1023
Sphaceloma, fawcettii Jenkins, cause of lesions on Citrus leaves, 539–545; **symphoricarpi,** n. sp., causing anthracnose of Symphoricarpos albus var. laevigatus, 799–800
Sphaerella tussilaginis, lesions produced on Tussilago farfara, 745–746
Sphaerotheca humuli, causing powdery mildew of raspberry, 787–788
Spike disease of sandal (Santalum album Linn.), occurrence of intracellular bodies in, 815–817
Spinach, host of beet curly top, 709–710
Spindle tuber, of potato, transmission of, 140; transmission by grasshoppers, 445–448
Spores, measurements, method of, 19–20; single, apparatus for isolating, 1017–1021; single, method for isolating, 17–19
Sporotrichum fruit spot of apple, 145
Stability of physiologic forms of Puccinia graminis tritici under diverse cultural conditions, 108–113
Stain, Giemsa, demonstration of bacteria in plant tissues by means of, 803–807
Staining, differential, of Peronosporaceae, 869–872
STAIR, E. C., H. D. BROWN, and T. E. HIENTON, Forced ventilation as a means of controlling tomato Cladosporium and Septoria in hotbeds, 1027–1029
STAKMAN, E. C., and E. B. LAMBERT, The relation of temperature during the growing season in the spring-wheat area of the United States to the occurrence of stem-rust epidnmics, 369–374; J. J. CHRISTENSEN, and H. E. BREWBAKER, Physiologic specialization in Puccinia sorghi, 345–354
Steam sterilization of coniferous seed beds, 952
Steironema ciliatum, lesions produced by Septoria conspicua, 732–733
Stellaria species, alternate hosts of a fir-needle rust, 705–708
Stem-end rot, varietal susceptibility of potatoes to Fusarium wilt and, 307–309
Stemphylium, congestum, n. sp., cause of apple rot, 576; type of fungi, relation to apple rots, 565–578
Stem rot, of sweet potato, prevented by treating stems and roots with Bordeaux mixture, 152–153
Stem rust, see Puccinia graminis
STEVENS, NEIL E., and HENRY F. BAIN, Storage rots of cranberries in 1927 crop, 809–814
STEWART, GEORGE, and D. W. PITTMAN, Predisposition of sugar beets to late root rot, 263–276
Stinking smut, of wheat, effect of washing seed on infection, 711–713
STONE, R E., see HOWITT, J. E.; Treatment of millet seed to prevent smut, 479
Storage, effect of disinfectants upon the germination of seeds kept in, for indefinite periods after treatment, 136; rots, of cranberries, in 1927, 809–814
STOUT, G. L., see TEHON, L. R.
STOVER, W. G., Experiments with tomato streak, 154
Strains, of Pseudomonas tumefaciens Sm. & Town. and their prevalence in various soils, 129–130; see physiologic specialization
Strawberry, dwarf, 439–444; killing of roots, 245–246
Streak, of tomato, experiments with, 154; of tomato, soil transmission of, 155; of tomatoes produced by disturbing principle from apparently healthy potatoes in combination with tomato-mosaic virus, 311
STREETS, R. B., Studies of Texas root rot in Arizona, 952–953
Stripe, barley, experiments on control of, 295–300; brown, of sugar cane, caused by **Helminthosporium stenospilum,** n.

sp., 135–136; brown, of sugar cane, in Cuba, 135; disease of barley, control of, 477–478; of hulless barley, control of, 139

Struthiopteris germanica, host of Uredinopsis struthiopteridis, 705–708

Studies, of black root rot of apple, 145; of the history of development of wound overgrowths on apple grafts and of the influence of wrappers on their suppression, 128; on crown-gall transplants, 130; on snapdragon rust, Puccinia antirrhini, 150; on the attenuation of plant viruses, 156; on the host range of aster yellows, 156; on the life history of the crown-gall organism; 128–129; upon the Fusarium wilt of China aster, 150; with watermelon wilt, caused by Fusarium niveum E. F. Sm., 143–144

Study, of citrus-blast and some allied organisms, 952; of pathogenic and non-pathogenic strains of Pseudomonas tumefaciens Sm. & Town., 331–343

Sugar beet, curly top, 951; occurrence of **Aphanomyces cochlioides**, n. sp., on, 149; transmission of curly-top virus through different solutions, 675–679

Sugar beets, diseases in storage resulting from hook injury, 939–941; filtration experiments on curly top of, 681–690; predisposition of, to late root rot, 263–276

Sugar cane, brown stripe of, 761–772; brown stripe of, caused by **Helminthosporium stenospilum**, n. sp., 135–136; brown stripe of, in Cuba, 135; effect of manganese deficiency on Pahala blight, 775–786; eye spot, ocellum as cause, 757–761, 763–770; eye spot, in Cuba, 135; gummosis of, 135; helminthosporiose of, 754–758; observations on mycorrhizae and their relation to root diseases of, 249–261; three Helminthosporium diseases of, 753–774

Sugar solutions, effect on beet curly-top virus, 675–679; for experimental control of teliospore and urediniospore formation, 184–199

Sulphur, dust, for control of leaf and stem rust, field trials, 480; dust, for control of leaf and stem rust, small-plot, 480; factors affecting the fungicidal property of, 147; fungicides, in the control of apple scab, 146–147; oxidizing agents in, to increase fungicidal activity, 1026–1027

Susceptibility, of potato varieties to Bacillus mesentericus, B. carotovorus, B. phytophthorus, and B. aroideae, 819–838; of wheat varieties, effect of ecological factors on, 81–108; see resistance; varietal, of potatoes to Fusarium wilt and stem-end rot, 307–309

Sweet potato, soil rot or pox in, caused by an Actinomycete, 152; stem rot, prevented by treating stems and roots with Bordeaux mixture, 152–153

Sweet potatoes, treatment of, with various disinfectants for black-rot control, 153–154

SWEZY, OLIVE, see SEVERIN, HENRY H. P.

Symphoricarpos albus var. laevigatus, anthracnose of, 797–801

Symplocarpus foetidus, lesions produced by Cercospora symplocarpi, 736

Take-all, see Ophiobolus graminis

Taraxacum officinale, Puccinia taraxaci on, experimental control of teliospore and urediniospore formation, 175–176, 196–197

TEHON, L. R., and G. L. STOUT, An ascomycetous leaf spot of cowpea, 701–704

Teliospore formation, experimental control of, 157–213

Temperature, chambers, constant-control, 227–238; effect of, on development of potato-tuber rots, 823–827; effect on growth of physiologic forms of cereal smuts, 972–981; optimum, for germination of Puccinia glumarum, 481; relation of, to occurrence of stem-rust epidemics, 369–374; relation to development of ascigerous stage of Venturia inaequalis, 396–409; relation to experimental control of teliospore and urediniospore formation, 163–180; relations of Cladosporium, 322–324; relations, on culture media, of Bacillus aroideae, carotovorus, mesentericus, phytophthorus, 822–823

Terminology, a question of correct usage, 460
Testimonial to ERWIN FRINK SMITH, 1–5
Thistle, Puccinia suaveolens on, experimental control of teliospore and uredinio-spore formation, 169–172, 191–192, 206
THOM, CHARLES, see MCCULLOCH, LUCIA
THOMAS, H. E., Killing of strawberry roots, 245–246; Root and crown injury to apple trees, 547–551
THOMAS, HALOLD E., see SMITH, RALPH E.
THOMAS, R. C., see SAYRE, J. D.
THOMPSON, DOROTHY, see MAINS, E. B.
Thread blight, caused by Corticium koleroga, 147–148
Tilletia, levis, effect of washing seed on infection, 711–713; levis, new physiologic forms of, 579–588; levis, pathogenicity of physiologic forms of, 985–992; levis, varietal resistance of spring wheat to, 981–992; tritici, new physiologic forms of, 579–588; tritici, new physiologic forms of, in wheat, 139; tritici, pathogenicity of physiologic forms of, 985–992
Timothy infusion, effect of different ages of, on growth of tobacco and on brown root rot of tobacco, 131–132
Tip burn of Irish potatoes, relationship of insect carriers to development of, 141
Tissues, plant, cytological studies of, affected with mosaic diseases, 154; plant, demonstration of bacteria in, by means of Giemsa stain, 803–807; plant, differential staining of Peronosporaceae in, 869–872; plant, migration of Bacterium tumefaciens in, of tomato, 553–564; plant, penetration of furfural in, 152; plant, relation of leaf infection to production and of time of leaf fall to development of ascigerous stage of Venturia inaequalis, 375–393
Tobacco, black root rot of, and soil reaction, 131; cigar effects of lime on, 130–131; effect of timothy infusion of different ages on the growth of, 131–132; effects of mosaic upon chlorophyll content of, 697–700; experiments and observations on control of true mosaic of, 132; influence of cropping systems and fertilizers on black and brown root rot of, 131; mosaic virus, accuracy in comparing various concentrations of, 132; ring spot, 133; virus diseases of, in Kentucky, 132–133
Tomato, control of Cladosporium and Septoria of, by means of forced ventilation in hotbeds, 1027–1029; curly top, or yellows, 709–710; experiments with streak of, 154; method and rate of migration of Bacterium tumefaciens in, 129; migration of Bact. tumefaciens in tissue of, 553–564; mosaic and streak of, soil transmission, 155; susceptibility to Bacillus aroideae and B. phytophthorus, 834–835; western yellow blight, or yellows, 709–710; yellows or tomato curly top, 709–710
Tomatoes, "streak" of, produced by disturbing principle from healthy potatoes in combination with tomato-mosaic virus, 311
TOMPKINS, C. M., and S. B. NUCKOLS, Development of storage diseases in sugar beets resulting from hook injury, 939–941
Topography in relation to severity of stem-rust epidemics, 90–91
Toxicity, lime-sulphur, nature, 355–360
Transmission, mechanical, of mosaic of Lilium auratum, 1025–1026; of bean mosaic, 155; of black leg by seed-corn maggot, 459; of cucumber mosaic by aphis, 143; of potato spindle tuber by grasshoppers, 445–448; of potato spindle tuber by grasshoppers (Locustidae), 140; of the virus of curly top sugar beets through different solutions, 675–679; soil, of tomato mosaic and streak, 155
Transplants, studies on crown gall, 130
Tranzschelia punctata, action of lime sulphur on spores, 355–360
Treatment, of millet seed to prevent smut, 479; of soils infested with Plasmodiophora brassicae, 141–142; of sweet potatoes for black-rot control, 153–154
Treatments, dust, for oat smuts, 139
Trees, nursery, apple and quince, overgrowths and hairy root on, 126
Trichoderma lignorum, 949
Trifolium, hybridum, Uromyces trifolii on,

experimental control of teliospore and urediniospore formation, 172–175, 188–191, 206; pratense, lesions produced by Pseudopeziza trifolii, 742

Triticum, vulgare, inheritance of resistance to Puccinia graminis in a cross between two varieties of, 631–658; vulgare, P. triticina on, experimental control of teliospore and urediniospore formation, 179, 195–196

Turf diseases, control of, with mercury, 137

Turnip, susceptibility to Bacillus carotovorus, B. aroideae, and B. phytophthorus, 833–835

Tussilago farfara, lesions produced by Sphaerella tussilaginis, 745–746

Uniform wheat-rust nurseries, 13–17, 20–31

Urediniospore formation, experimental control of, 157–213

Uredinopsis, copelandi, on Athyrium cyclosorum and Felix bulbifera, 705–708; macrosperma, on Pteridium aquilinum and P. pubescens, 705–708; mirabilis, on Woodwardia areolata and Onoclea sensibilis, 705–708; osmundae, on Osmunda species, 705–708; phegopteridis, on Phegopteris dryopteris, 705–708; struthiopteridis, on Woodwardia virginica and Struthiopteris germanica, 705–708

Uredo alpestris, 670

Uromyces, appendiculatus on Phaseolus vulgaris, experimental control of teliospore and urediniospore formation, 163–169, 183, 184–187, 206; polygoni on Polygonum aviculare, experimental control of teliospore and urediniospore formation, 178–179, 206; scillarum, 672; trifolii on Trifolium hybridum, experimental control of teliospore and urediniospore formation, 172–175, 188–191, 206

Ustilago, avenae, cultural differences between physiologic forms of, 969–972; avenae, effect of temperature on growth of physiologic forms of, 981; avenae, varietal resistance of oats to, 993–997; crameri, 911–912; hordei, cultural differences between physiologic forms of, 964–968; hordei, effect of temperature on growth of physiologic forms of, 979–981; hordei, pathogenicity of physiologic forms of, 992–993; levis, cultural differences between physiologic forms of, 969; levis, effect of temperature on growth of physiologic forms of, 981; levis, varietal resistance of oats to, 993–997; nuda, cultural differences between physiologic forms of, 962–964; nuda, effect of temperature on growth of physiologic forms of, 976–979; striaeformis, two physiologic forms of, 149; tritici, cultural differences between physiologic forms of, 960–962; tritici, effect of temperature on growth of physiologic forms of, 973–976; zeae, influence of environmental factors on seasonal prevalence, 589–598; zeae, losses due to smut infection in selfed lines of corn, 599–602

Vaccinium, mycorrhizal fungus, of, 148; species, alternate hosts of fir-needle rusts, 705–708

VALLEAU, W. D., and E. M. JOHNSON, Experiments and observations on the control of true tobacco mosaic, 132; Some virus diseases of tobacco in Kentucky, 132–133

van der BIJL, P. A., see BIJL, P. A. van der

Varietal, resistance of watermelons to wilt (Fusarium niveum), 144; susceptibility of potatoes to Fusarium wilt and stem-end rot, 307–309

Velvet bean, bacterial spot of, 460

Ventilation, forced, as a means of controlling tomato Cladosporium and Septoria in hotbeds, 1027–1029

Venturia, cerasi, 328; inaequalis, 943–944; inaequalis, certain sulphur fungicides in the control of apple scab, 146–147; inaequalis, effect of environment upon, 375–418; inaequalis, factors important in development of perithecia of, 145–146; inaequalis, fall application of fungicides in relation to apple-scab control, 146

Verbascum blattaria, lesions produced by Septoria verbasicola, 733–734

Verticillium, albo-atrum, reaction of plant

stems to products of, 604–605; wilt of heliotrope, 246
Vinca rosea, occurrence of intracellular bodies in spike disease of, 815–817
Virus, beet curly-top, transmission through different solutions, 675–679; disease, of tobacco, ring spot, 133; diseases observed by the Allison V. Armour Expedition, 155; diseases, of tobacco in Kentucky, 132–133; of sugar beet curly top, 951; tobacco-mosaic, accuracy in comparing various concentrations of, 132; tomato-mosaic, a streak of tomatoes produced by disturbing principle from healthy potatoes in combination with, 311
Viruses, plant, studies on attenuation of, 156

WALKER, J. C., and F. L. WELLMAN, A Fusarium-resistant cabbage of Jersey Wakefield type, 142
WALKER, M. N., see DOOLITTLE, S. P.
Walnut, crown rot, of, 948–949
Warty disease, or black scab, of potato, in Belgium, 126
Washing seed, effect on wheat-stinking-smut infection, 711–713
Washingtonia robusta, leaf spot due to Cylindrocladium macrosporum, 219–225
Watermelon, studies with wilt of, caused by Fusarium niveum, 143–144; varieties of, resistant to wilt (Fusarium niveum), 144
WATERS, CHARLES W., The control of teliospore and urediniospore formation by experimental methods, 157–213
Weather in relation to severity of stem-rust epidemics, 91–105
WEBER, GEORGE F., Biography of OWEN, F. BURGER, 627–630; Cucumber fruit rot and angular leaf spot, 133
WELLMAN, F. L., The reaction and treatment of soils infested with Plasmodiophora brassicae Wor., 141–142; see WALKER, J. C.
WELSH, J. N., see GOULDEN, C. H.
Western yellow blight of tomatoes, or yellows, 709–710
Wheat, effect of ecological factors on susceptibility of varieties of, to Puccinia graminis tritici, 81–108; effect of washing seed on stinking-smut infection, 711–713; inheritance of resistance to Puccinia graminis tritici in a cross between two varieties of, 631–658; new physiologic forms of Tilletia tritici in, 139; physiologic forms of stem rust in Canada, 478–479; Puccinia triticina on, experimental control of teliospore and urediniospore formation, 179, 195–196; reaction to take-all in Canada, 477; rust epidemics, 369–374; smut, physiologic forms of, 579–588; spring, varietal resistance to Tilletia levis, 981–984
WHETZEL, H. H., The crown-elongation disease of the peony, 243–244
White spot of alfalfa, caused by irrigation, 136–137
WILLIAMS, ROBERT, see YOUNG, H. C.
WILSON, E. E., Factors important in the development of perithecia of Venturia inaequalis, 145–146; see KEITT, G. W.; Studies of the ascigerous stage of Venturia inaequalis (Cke.) Wint. in relation to certain factors of the environment, 375–418
Wilt, Fusarium, and stem-end rot, varietal susceptibility of potatoes to, 307–309; (Fusarium niveum), of watermelon, varietal resistance to, 144; Fusarium, of China aster, 150; relation of fungous products to, 603–610; Verticillium of heliotrope, 246; watermelon, studies of, 143–144
Wilt-resistant cotton varieties, 134
WINGARD, S. A., and F. D. FROMME, Tobacco ring spot: A virus disease with a wide host range, 133
WOLF, FREDERICK A., Further observations on Corticium koleroga (Cke.) v. Hohn., 147–148
WOODROOF, NAOMI CHAPMAN, Cotton-seed treatment by the dusting method, 134
Woodwardia, areolata, host of Uredinopsis mirabilis, 705–708; virginica, host of U. struthiopteridis, 705–708
Wound overgrowth, correlation of, and crown gall of apple, 128
Wound overgrowths, studies of the history of development of, on apple grafts and

of the influence of wrappers on their suppression, 128

Wrappers, influence of, on the suppression of wound overgrowths, on apple grafts, 128

WRIGHT, WILLIAM H., and SKORIC, VLADIMIR, Demonstration of bacteria in plant tissues by means of Giemsa stain, 803–807

Xylaria mali, cause of black root rot of apple, 145

Yellows, aster, studies on host range of, 156; of potato, a new and destructive disease in Utah, 140–141; tomato, 709–710, 950

YOUNG, H. C., and ROBERT WILLIAMS, Factors affecting the fungicidal property of sulphur, 147

YOUNG, V. H., Notice of field meeting of the Southern Section of the American Phytopathological Society, 460–461

YU, T. F., see PORTER, R. H.

Zantedeschia aethiopica, susceptibility to Bacillus aroideae, 835–836

Zea mays, host of Pythium arrhenomanes, 873–875; Puccinia sorghi on, experimental control of teliospore and uredinio-spore formation, 179–180, 194–195, 206; see corn

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BIOMETRICAL STUDIES ON THE VARIATION OF PHYSIOLOGIC FORMS OF PUCCINIA GRAMINIS TRITICI AND THE EFFECTS OF ECOLOGICAL FACTORS ON THE SUSCEPTIBILITY OF WHEAT VARIETIES[1]

MOSES N. LEVINE[2]

INTRODUCTION

The question whether specialized forms of *Puccinia graminis* Pers. are plastic or constant is not only of considerable scientific interest but also of paramount economic importance. Breeding for rust resistance can be successful only in so far as the different rust forms will maintain their stability,

[1] Presented to the Faculty of the Graduate School of the University of Minnesota as a thesis in partial fulfillment of the requirements for the degree of Doctor of Philosophy, granted December 18, 1924. Cooperative investigations between the Bureau of Plant Industry of the United States Department of Agriculture and the Agricultural Experiment Station of the University of Minnesota. The uniform rust nursery experiment in this investigation was started in 1919 by the Office of Cereal Crops and Diseases in cooperation with various state agricultural experiment stations at the instance of Drs. H. B. Humphrey, C. E. Leighty, and E. C. Stakman. In 1920, the cooperation of the Dominion of Canada Department of Agriculture was secured for extending the experiment to the grain-growing region of Western Canada.

[2] Associate Pathologist, Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture. The writer takes pleasure in acknowledging his indebtedness to Dr. E. C. Stakman, Professor of Plant Pathology, University of Minnesota, and Pathologist, Bureau of Plant Industry, United States Department of Agriculture, at whose suggestion the research was undertaken, for the stimulating encouragement and helpful criticism he afforded during the progress of the investigation. To Messrs. J. Allen Clark, Agronomist, and John H. Martin, formerly Associate Agronomist, Western Wheat Investigations, Office of Cereal Crops and Diseases, U. S. Department of Agriculture, the writer is indebted for having grown the seed for the uniform rust nurseries at Moccasin, Mont., and for kindly distributing it to the different cooperators. The writer is under obligation to Professor W. P. Fraser, formerly Pathologist in Charge of Cereal Disease Investigations in the Dominion of Canada Department of Agriculture, and to the workers at the different agricultural experiment stations in the United States, under whose auspices the uniform rust nurseries were maintained, for their excellent cooperation and numerous courtesies. Sincere thanks also are due Dr. J. Arthur Harris,

i.e., so long as they will not "adapt" themselves easily to new varieties and will not be readily influenced by changing conditions. What rôle environmental conditions play in "predisposing" cereal crops to the attack of the stem-rust fungus is another serious question that deserves the careful consideration of agronomists as well as phytopathologists.

Extensive studies have been made by various workers on the effect of host plants and other factors on the parasitic capabilities and the morphologic structures of different forms of stem rust. [See Freeman and Johnson (11), Stakman and Piemeisel (35), Stakman and Levine (29, 30), Newton (20), and Levine (15) for literature reviews and original research on this subject.] These studies have been confined, however, almost entirely to the composite group-forms, or varieties, of *P. graminis*.[3] In recent years certain knowledge has been gained concerning the intricate nature of a few of the component strains, or physiologic forms, of the *tritici*, *avenae*, and *secalis* varieties (20, 30, 13, 3, 16, 23, 32, 39, 5, 31). But as yet very little can be found in literature concerning the effects of ecological factors on the predisposition of cereal crops to the ravages of stem rust; and still less regarding the fixity and comparative morphology of the physiologic forms comprising the different varieties of *Puccinia graminis*.

The varieties of *Puccinia graminis* Pers. now known to be endemic on the North American continent are as follows:[4]

1. *P. graminis tritici* Erikss. and Henn.; some 40 physiologic forms are known (30).
2. *P. graminis secalis* Erikss. and Henn.; about a dozen separate forms are known (16).
3. *P. graminis avenae* Erikss. and Henn.; five physiologic forms have been described (32, 5).
4. *P. graminis phleipratensis* (Erikss. and Henn.) Stak. and Piem.; has not been separated into forms (35).
5. *P. graminis agrostis* Erikss.; has not yet been separated into forms (35).

Head, Department of Botany, University of Minnesota, Dr. Clyde E. Leighty, Agronomist, Office of Cereal Crops and Diseases, U. S. Department of Agriculture, and Dr. Holbrook Working, formerly Associate Professor, Agricultural Economics, University of Minnesota, for valuable suggestions pertaining to the statistical data presented in this paper. Finally, to Dr. C. R. Ball, Senior Agronomist in Charge, and to Drs. H. B. Humphrey and A. G. Johnson, Senior Pathologists, Office of Cereal Crops and Diseases, U. S. Department of Agriculture, the writer is under obligation for reading and editing this manuscript.

[3] In conformity with the resolution recently adopted by the American Phytopathological Society conjointly with the American Society of Agronomy and the Mycological Section of the Botanical Society of America (4), the term "variety" is hereinafter used to designate the composite group-forms of *P. graminis;* the term "form," or "physiologic form," refers to a specialized race within a given "variety"; Arabic numerals are employed to designate the several physiologic forms within a given variety.

[4] For list of host plants see Stakman and Piemeisel (35), Stakman and Levine (31), and Bailey (5).

6. *P. graminis poae* Erikss. and Henn.; existence of physiologic specialization has not definitely been established (31).

Historical Review

It has been commonly observed that the prevalence and severity of epidemics of stem rust depend not only on the presence of sufficient quantities of aecial or uredinial material in the spring, but also on meteorological conditions favorable for infection, such as proper temperature, abundant moisture, and sufficient sunshine. Bolley (7) states that dew and cool temperature favor rust infection. In Carleton's opinion, the prevalence of the disease is dependent largely on the humidity of the atmosphere (9). According to Butler and Hayman (8), "moisture as indicated by cloud and, to a lesser extent, an excess of water in the soil induce rusting of the crop." Sorauer (25) states that sharp differences between clear cold nights and hot days with abundant dew are especially favorable for rust infection. Freeman and Johnson (11) thought that the "unusually low temperature in 1904 was a very important factor, if not the determining factor, for the rust epidemic of that year."

Stakman and Levine (29) found that the optimum atmospheric temperature for the development of stem rust on wheat in the greenhouse ranges between 66.5° and 70.0° F. [about 19° to 21° C.]. They also found that a sufficiency of moisture and plentiful light are indispensable for the best growth of the rust. A detailed greenhouse study with two physiologic forms of *P. graminis tritici* led Peltier (23) to conclude that the optimum temperature for the initial infection of, and subsequent development on, susceptible varieties "in the seedling, stooling, and jointing stages was between 20° and 25° C. [68°–77° F.]. No infection occurred at temperatures of 10° C. [50° F.] and below, while only a few plants of some differential hosts were infected at 15° C. [59° F.] and 30° C. [86° F.]. With plants at the heading stage a lower optimum temperature for infection occurred in that no rust developed at 30° C. [86° F.], while it did at 10° C. [50° F.]." Tehon and Young (37) are of the opinion that a mean temperature of 71.5° F. may be considered as indicating the probable optimum for stem-rust infection under field conditions in Illinois. They also hold that there is an apparent correlation between periods of precipitation and the occurrence of infections. Beauverie (6) ascribes the absence of stem rust from the wheat varieties grown at Limagne and Clermont, France, in 1921, to the fact that there was no rain there until harvest time. In 1922 the rainfall at these localities was frequent and often abundant, and *Puccinia graminis* "became more and more prevalent as the season advanced." These observations led Beauverie to the conclusion that "*P. graminis* is essentially the rust of wet seasons."

Marchal (17) states that, besides weather conditions, the following factors favor the appearance of rust, *viz.*, soil moisture, stiff soil, shade, late sowing, and misuse of fertilizers. Vavilov (38) reported that neither early nor late sowing, nor the application of nitrogenous fertilizers to the soil exerted any influence on the infection capabilities of *Puccinia triticina* Erikss. Resistant varieties remained resistant under these conditions, and the reaction of susceptible varieties likewise was unaltered. Stakman and Aamodt (27), on the basis of their observations and experiments covering a period of eight years, concluded that, "while the direct effect of fertilizers on the development of stem rust seems to be slight, there is sometimes a profound indirect effect. The stem-rust attack sometimes is more severe on plants grown on soil heavily fertilized with nitrogenous manures." This, they believe, is due to the increased density of stand and delayed maturity, which make conditions for infection more favorable on account of close proximity of the plants on one hand, and the lengthening of the period during which the plants could become infected on the other. However, they found that the inherited tendency to resistance or susceptibility in a variety could not be changed fundamentally by the application of fertilizers.

Hursh (14) showed that the mycelium of *P. graminis* within the stem of the host is limited almost entirely to the chlorenchymatous tissue; and, as the only important chlorenchymatous tissue of the stem is the collenchyma, the rust mycelium can grow only in this tissue. Furthermore, he found that excessive fertilization with nitrogen has a tendency to decrease the amount of sclerenchyma in proportion to the amount of collenchyma, and, for this reason, plants heavily fertilized with nitrogen may be more severely injured by rust than those which have not been so fertilized. Weiss (40) states that "the addition of NaCl or NaH_2PO_4 to the basic three-salt nutrient solution did not affect the susceptibility of wheat to leaf rust or stem rust. The addition of $NaNO_3$ resulted in somewhat readier infection in each case but did not predispose to greater injury. KCl retarded infection in proportion to the diminution of growth of the host, particularly when used in excess. $CaCl_2$ and $MgCl_2$ appeared to induce a state in which the host was less readily susceptible to infection. $CaCl_2$ also resulted in a reduction of water requirement, about 10 per cent for tops and 40 per cent for grain." Stakman, Parker, and Piemeisel (34) observed seasonal fluctuations in the severity of infection of stem rust, but their experimental results and field observations indicate that rust resistance is a rather constant genetic character and is not controlled primarily by seasonal conditions, soil type, geographical location, or other cultural conditions, but the resistance of grain varieties may and does vary in different regions because of the presence of different physiologic forms of the rust pathogene.

In addition, then, to the presence of sufficient inoculum and the prevalence of favorable environmental conditions for infection, even on susceptible sorts, the presence of particular physiologic forms of *P. graminis tritici* is necessary for the development of epidemics on certain varieties of wheat. Stakman, Levine, and Leach (33), after having discovered the first dozen forms of *P. graminis tritici*, came to the conclusion that "the fact that the same variety of wheat may be immune in one locality and susceptible in another is clearly explained. Formerly recourse was taken to the theory that environmental conditions changed the physiologic processes and materials of wheat varieties so fundamentally that the resistance of the plants broke down. The real explanation of this phenomenon, however, is the fact that there are many biologic forms of the rust fungus." Hayes and Stakman (12), therefore, hold that further studies are necessary to determine the number and prevalence of the physiologic forms of *P. graminis tritici* which should be cultured and used experimentally in definite attempts to produce wheat varieties resistant to all forms occurring in the wheat-growing regions. Consequently a knowledge of the constancy in the parasitic behavior of these forms is obviously one of the outstanding desiderata connected with such studies.

Ever since Eriksson (10) first discovered the existence of the group-forms, or varieties, of *P. graminis* there has been a good deal of speculation as to the degree of fixity of these forms. The literature dealing with this subject has been rather fully reviewed by Stakman, Piemeisel, and Levine (36). It shall, therefore, suffice to summarize here briefly the experimental results of the latter investigators. Successive transfers of *P. graminis tritici*, *P. graminis avenae*, *P. graminis phleipratensis*, and *P. graminis agrostis* to resistant hosts did not increase their virulence. There was no indication of their gradual adaptation to resistant or semi-congenial hosts, although plus and minus fluctuations occurred. The pathogenicity of the forms did not seem to be changed either easily or permanently by host influence. No one so-called "bridging host," nor any combination of such hosts, enabled any of these rust varieties to attack naturally immune hosts nor to infect more readily highly resistant plants.

Although neither host plants nor cultural conditions seem to affect the genetic nature of the different rust varieties, Stakman and Levine (29) observed that resistant varieties and adverse environment invariably tend to decrease the size of the uredinia and urediniospores of the stem-rust fungus. However, as soon as the unfavorable condition of host and environment are removed, the spores regain their normal size in a single generation. Levine (15) later found that the aeciospores and teliospores of the different rust varieties responded to unfavorable conditions in much the same manner as the urediniospores.

These variations within a given variety of *P. graminis* are not to be confused with the inherent morphologic differences between the various group-forms *per se*. Stakman and Levine (29, 31) found a consistent difference in the color, shape, and size of the urediniospores of all the varieties of *P. graminis*, when produced under uniform conditions. Levine's (15) subsequent statistical studies show that these varieties differ distinctly and significantly in the size of aeciospores and teliospores as well as urediniospores. In general, *P. graminis tritici* has the largest spores; *P. graminis avenae* occupies the second place; *P. graminis secalis*, third; *P. graminis phleipratensis*, fourth; *P. graminis agrostis*, fifth; and *P. graminis poae* has the smallest spores of all.

Stakman and Levine (29) found that the group of physiologic forms to which the hard red spring wheat varieties as a class are highly resistant possessed urediniospores which were consistently, though not very greatly, smaller than the urediniospores of the group of forms which parasitizes the hard red spring wheats very readily. Waterhouse (39) detected morphological differences in the two physiologic forms of the wheat stem-rust fungus which he discovered in Australia. He found that his form 1 has a mean length of more than one micron less than form 2, but the mean width of the first form is nearly four microns greater than that of the second form. He also states that "a casual examination of the uredospores gives the impression that the average spore of form 2 is more slender than that of form 1." In addition to differences in parasitism, Bailey (5) observed significant differences in the size of the urediniospores of the several physiologic forms of *P. graminis avenae* when all were grown under identical conditions.

Hursh (13) demonstrated distinct differences between *P. graminis tritici* 11 Stak. and Lvne. and *P. graminis tritici* 27 Stak. and Lvne. with respect to their germination response to extremes of hydrogen-ion concentration and temperature. Allen (3) found but little difference between forms 3 and 19 Stak. and Lvne. in their effect upon the stomata of wheat varieties. On the whole, from 3 affected Baart wheat more strongly, but the difference in the action of the two forms on the stomata of Kanred and Mindum was hardly perceptible, although the two rusts differ greatly in their ability to parasitize these varieties.

In view of all these facts it seemed desirable to make more systematic and extensive observations in the field concerning the effects of ecological factors on the severity of stem-rust epidemics, and to conduct more intensive studies in the greenhouse and laboratory to obtain further evidence relative to the idiosyncrasies and the stability of the physiologic forms of *P. graminis tritici*.

Purposes of Investigation

The purposes of the present investigation were:

1. To determine the degree of resistance to stem rust of varieties of spring wheat and emmer in the wheat-growing regions of the United States and Canada, under natural climatic and edaphic conditions.

2. To study the rust reaction of these varieties in the field in the presence of physiologic forms of *Puccinia graminis tritici*, capable of attacking them readily in the greenhouse, and *vice versa*.

3. To ascertain the number and distribution of physiologic forms of *P. graminis tritici* in different parts of the spring wheat region.

4. To determine the identity and nature of these forms by means of artificial inoculations on differential varieties of *Triticum spp.*

5. To determine by means of statistical studies the comparative morphology of some of these forms.

6. To determine the effect of prevailing weather conditions, condition of host plant, amount of inoculum, diverse cultural practices, etc., on the severity of infection of stem rust on wheat in the field.

7. To study the constancy of these forms under varying cultural conditions, and the effect of geographical location and host plant on their pathogenicity and stability.

EXPERIMENTAL MATERIALS AND METHODS

The nature of the present investigation was twofold: first, observational; and second, experimental. The observations were made over a period of five years on a series of uniform rust nurseries grown in different localities. The experimental phase consisted of greenhouse and laboratory studies, some of the experiments having been conducted for as long as six and nine years.

Uniform Rust Nurseries, Names of Cooperators, Varieties Tested

A series of nurseries, each consisting of a uniform set of wheat varieties, was established at various points in the United States and Canada (See figure 1 and table 1). These nurseries are hereinafter designated as uniform rust nurseries. The first year the uniform rust nurseries were maintained at 13 different experiment stations in the United States (Table 3). At some of the stations the nurseries were abolished the following year; however, several new stations were added in the United States and a similar uniform nursery experiment was started at eight stations in Canada (Table 4). In 1921 the uniform rust nurseries were in operation at 14 experiment stations in the United States and at 10 in Canada (Table 5). In 1922 and 1923 uniform rust nurseries were operated at 19 experiment stations in the United States, the cooperative experiment in Canada having been discontinued after 1921 (See tables 6 and 7). At St. Paul, Minn., there were two uniform rust nurseries during the last three years of the experiment (1921–1923). In one, the rust epidemic was induced arti-

ficially, using several physiologic forms as inoculating material; in the other, the infection was permitted to come about naturally. In 1923 there were two nurseries also at Coon Creek, Minn., one on a sand hill and one in a peat bog.

Seed for the uniform nurseries was grown under rust-free conditions at Moccasin, Montana, and was furnished the cooperators at the various experiment stations by the western wheat investigations project of the Office of Cereal Crops and Diseases, U. S. Department of Agriculture, each year, except 1920. In that year the cooperators used the seed they obtained from the 1919 harvest of their respective nurseries.

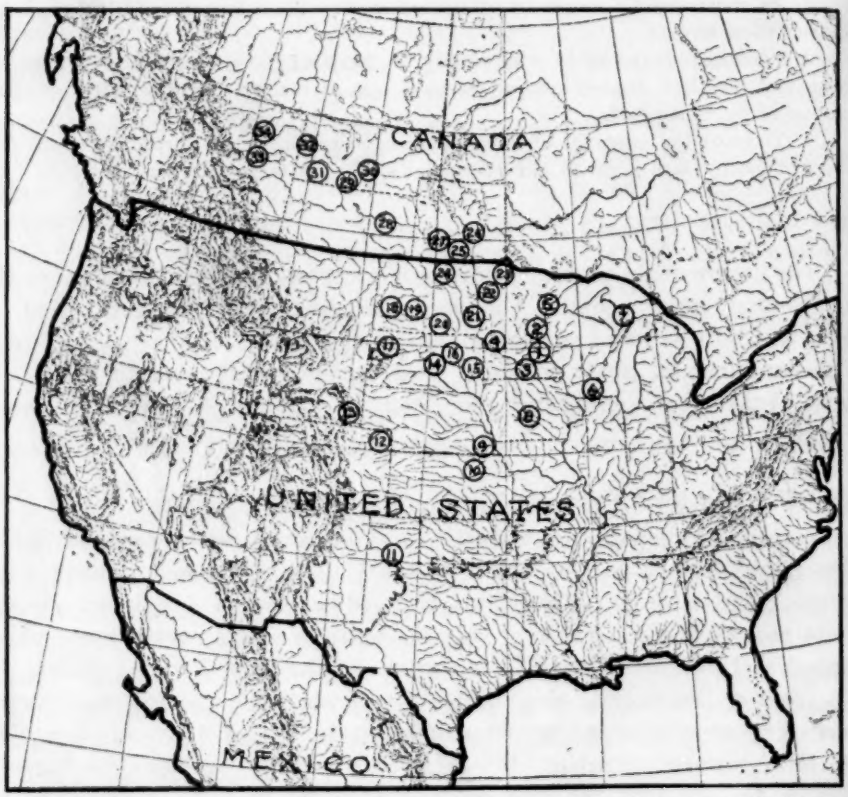


FIG. 1. Location of uniform rust nurseries at 34 experiment stations in the United States and Canada during one or more years of the five-year period, 1919–1923, inclusive.

The maximum number of varieties grown during any one season in the course of the present experiment was 24. Some were known to be generally resistant to stem rust under field conditions, *e.g.*, Acme, Monad, Pentad, and

TABLE 1.—*Location of uniform rust nurseries in the United States and Canada, and names of cooperators at each station*

Map no.	Experiment station	Cooperators
1	St. Paul, Minn.	H. K. Hayes, O. S. Aamodt
2	Coon Creek, Minn.	G. H. Nesom
3	Waseca, Minn.	R. E. Hodgson
4	Morris, Minn.	R. O. Bridgford
5	Duluth, Minn.	M. J. Thompson, H. C. Gilbert
6	Madison, Wis.	J. G. Dickson
7	Chatham, Mich.	G. H. Coons, J. E. Kotila
8	Ames, Iowa	S. M. Dietz
9	Lincoln, Nebr.	T. A. Kisselbach
10	Manhattan, Kans.	L. E. Melchers, J. H. Parker
11	Amarillo, Tex.	J. F. Ross
12	Akron, Colo.	F. A. Coffman
13	Archer, Wyo.	A. L. Nelson
14	Highmore, S. Dak.	E. S. McFadden
15	Brookings, S. Dak.	A. T. Evans, Matthew Fowlds
16	Redfield, S. Dak.	Samuel Garver
17	Newell, S. Dak.	A. D. Ellison
18	Dickinson, N. Dak.	R. W. Smith
19	Mandan, N. Dak.	J. C. Brinsmade, Jr.
20	Edgeley, N. Dak.	W. E. Brentzel, O. A. Thompson
21	Fargo, N. Dak.	W. E. Brentzel
22	Crookston, Minn.	R. S. Dunham, E. R. Clark
23	Golden Valley, Minn.	G. H. Nesom
24	Langdon, N. Dak.	W. E. Brentzel, Louis Jorgenson
25	Morden, Manitoba	W. P. Fraser
26	Winnipeg, Manitoba	
27	Brandon, Manitoba	
28	Indian Head, Saskatchewan	
29	Saskatoon, Saskatchewan	
30	Rosthern, Saskatchewan	
31	Scott, Saskatchewan	
32	Vermillion, Alberta	
33	Lacombe, Alberta	
34	Edmonton, Alberta	

Kota; others were included because of their early maturity, *e.g.*, Prelude and Ruby; and still others were important commercial varieties in the United States and Canada, as, for example, Marquis, Power, Kubanka, Arnautka, and Mindum. Varieties which are essential in the determination of the physiologic forms of *P. graminis tritici*, such as Kubanka durum (C. I. 2094), Arnautka ("Speltz Marz") durum (C. I. 6236), and Vernal (White Spring) emmer (C. I. 3686) also were included. Little Club, which is completely susceptible, and Khapli, which is extremely resistant to all

known physiologic forms in North America, were added because of their contrasting differences. The varieties used in one year or another are listed in table 2.

A physiologic form of *P. graminis tritici* has been found recently to which the behavior of Little Club and Khapli emmer has been reversed. This form was isolated from a rusted specimen of Federation wheat grown at Giza, Egypt. It attacks Khapli rather severely in both the seedling and post-heading stage; Little Club shows considerable resistance in all stages of development, especially under deficient light conditions.

TABLE 2.—*Varieties of wheat and emmer grown in uniform rust nurseries to determine their reaction to stem rust under field conditions*

Class and variety	Cereal investigations accession number
Durum (*Triticum durum* Desf.):	
Kubanka	1440
Do	2094
Do	4063
Arnautka	1493
Do	4064
Do "Speltz Marz"	6236
Mindum	5296
Acme	5284
Monad	3320
Pentad	3322
Kahla	5529
Peliss	1584
Hard Red Spring (*Triticum vulgare* Vill.):	
Haynes Bluestem	2874
Marquis	3641
Power Fife	3697
Ruby	6047
Kitchener	4800
Red Bobs	6255
Preston	3081
Kota	5878
Prelude	4323
White Club (*Triticum compactum* Host.):	
Little Club	4066
Emmer (*Triticum dicoccum* Schrk.):	
Vernal (White Spring)	3686
Khapli	4013

In 1919 and 1920 only 18 of the 24 varieties enumerated in table 2 were grown. These included the three strains of Kubanka, two strains of Arnautka (C. I. 4064 and C. I. 6236) and Mindum, Acme, Monad, and

Pentad of the durum class; all of the hard red spring varieties listed, except Kitchener and Red Bobs; and both of the emmer varieties. In addition to these, two hybrids were included, namely, Kubanka × Haynes (C. I. 4788) and Kubanka × Preston (C. I. 4789). In 1921 and 1923 the complete set as given in table 2 was used. In 1922 Kubanka (C. I. 2094) and Arnautka (C. I. 6236) were omitted on account of lack of seed.

In 1919 and 1920 each variety was grown in three adjacent rod rows. The rate of seeding was 16 grams per row for wheat and 20 grams for emmer. Duplicate sowings were made at each station at an interval of about two weeks. Beginning with 1921 the sowing of each variety was reduced to two rod rows instead of three and to a single seeding instead of two.

Inoculation Technique and Cultural Methods in the Greenhouse

Specimens of fresh uredinial material were collected at the various uniform rust nurseries at the time the rust estimates were made. The material was sent to University Farm, St. Paul, where it was used promptly to inoculate as many of the differential varieties as possible. The inoculation and incubation methods followed were essentially the same as those described by Stakman and Piemeisel (35). Proper precautions were taken to reduce the amount of accidental infection to a minimum. The seedlings of the differential hosts were grown in a secluded section of the greenhouse. Immediately after inoculation the seedling plants were placed in galvanized iron incubation chambers, containing water to the depth of approximately one inch, and covered with glass frames. After 48 hours the inoculated plants were removed from the incubation chambers and placed in booths on the greenhouse benches. Partitions consisting of two layers of thick muslin separated the booths. Rust notes were taken 12 to 18 days later, depending on the season of the year and prevailing weather conditions. When all the differential varieties were tested and their reactions recorded, the identity of the physiologic forms in question was determined by means of the dichotomous key of Stakman and Levine (30).

Single-spore Isolations and Spore Measurements

A number of physiologic forms employed in this study were purified by means of single spore isolations. Isolating single urediniospores is tedious and painstaking, and it was found desirable to have two men perform the task, one doing the isolating and the other the inoculating.[5] This also afforded additional insurance of the accuracy of the procedure, for each

[5] The writer greatly appreciates the careful and efficient assistance in the monosporous culture work of Mr. Alfred E. Eagle, greenhouse and field foreman, Division of Plant Pathology and Botany, University of Minnesota.

spore picked up was checked by the assistant. To eliminate the possibility of chance contamination, the work was done where there were no rust cultures and behind a curtain designed to arrest any wind-borne spores which might be blown in from outside. Hands were thoroughly cleansed with soap and water, and incubation chambers (galvanized iron tanks and glass covers) were first steam sterilized for twenty minutes and then allowed to cool gradually. When cool, water to a depth of one inch was put in the tank and the incubation chamber was placed in spore-proof glass compartments, in which the inoculated plants were to remain thenceforth.

Two microscopes with low power objectives were used, one by the isolator and one by the inoculator. The first microscope was provided with a mechanical stage. A special metal contrivance (hereafter to be designated as "adjuster") was affixed to the stage of the second microscope.[6] Urediniospores of the physiologic form to be purified were scattered over a dry microscope slide by gentle tapping an infected blade of wheat. The spores were further separated with the aid of a dissecting needle prior to placing the slide in the mechanical stage. Single spores were picked up by the isolator by means of a finely pointed clean needle (Sharps 8 sewing needle) covered with a very thin film of vaseline. Upon examining the tip of the needle under the microscope and being satisfied that it bore a solitary urediniospore, it was handed over to the inoculator. The latter, without jarring it, placed the needle in the metal adjuster which was so arranged that the point of the needle was always maintained in the field of vision. While the needle was turned completely around, examination was made under the low power of the microscope. If more than one spore was detected, or if no spores could be noticed, another attempt was made to pick up a single spore.

When one spore only was adhering to the needle, the latter was removed from the adjuster by the right hand. Its point, containing the single spore, was then dipped in the tiny drop of water previously placed by means of a wooden toothpick within one-half inch from the tip of the leaf to be inoculated. The needle was then gently wiped on the leaf surface, care being taken not to injure the tissue. The leaf was kept in position by a toothpick held in the left hand, which was subsequently placed near the plant as a sign that it had been inoculated. When this was accomplished, the needle was again placed in the adjuster and examined to ascertain whether the spore had been removed. When no spore could be seen, it was assumed that the spore had been deposited on the plant. The needle

[6] The writer wishes to express his gratitude to Mr. Gilbert D. George, of the Division of Publications of the University of Minnesota, and the United States Department of Agriculture, for designing and manufacturing this device.

was then handed back to the isolator, who in the meantime had another needle charged with a single spore ready for the inoculator. Thus both workers were kept steadily busy, without having to adjust their eyes constantly to different objects, which would necessarily have been the case had one person done both the isolating and inoculating.

After all the plants in a pot had been inoculated and marked, the pot was immediately placed in the incubation chamber and the plants sprayed from above with an atomizer containing clean tap water. The temperature in the glass cage was kept as near 70° F. as possible during the incubation period of 48 hours. At first the percentage of successful infection from the monosporous isolations was very low, 0.18 per cent. It took 547 isolations to secure the first successful infection, but when conditions were just right, three infections were once obtained from only 57 isolations. On this occasion there was as high as 5.3 per cent of successful infection, the average being about 1 per cent.

Eight physiologic forms of *P. graminis tritici*, four of monosporous origin and four stock cultures, were subjected to a statistical morphologic study. Both diameters of each urediniospore under observation were measured and recorded. All of the spore measurements were made with a Zeiss screw micrometer attached to a calibrated Spencer microscope. Unconscious selection of spores for measurement was avoided by measuring all the spores which were encountered in passing from one end of the mount to the other. It was found that in virtually every case one hundred urediniospores were amply representative of the populations studied. The statistical constants were calculated by means of the accepted formulae. The odds against the chance occurrence of the differences obtained were ascertained according to the computations of Pearl and Minor (21). The shape of the urediniospores was determined by the method suggested by Rosenbaum (24). The mean length-to-width ratios of a number of physiologic forms determined by this process were compared with the ratios resulting from dividing the mean lengths of the respective forms by their mean widths, a method employed by some workers. The probable error of the quotient of the two quantities last named was derived by the formula given by Mellor (19, p. 529), which is as follows:

$$E = \pm \frac{\sqrt{\left(\frac{Ba}{A}\right)^2 + b^2}}{A}$$

where E stands for the probable error of the quotient (B : A), respectively affected by the probable error $\pm$ b and $\pm$ a.

As it was previously found (29) that the superficial layer of each uredinium contains larger spores, the urediniospores to be measured were

dusted into a drop of water on the microscope slide. In all other respects the method was the same as that in the previous experiments (29, 15).

RESULTS OF INVESTIGATION

The results of the observations on the reaction of the wheat varieties in the uniform rust nursery experiment are summarized in tables 3 to 8, inclusive. The physiologic forms isolated each year from the various nurseries are listed in table 9. Tables 10 and 11 show the behavior and distribution of these forms. The data on the morphology of certain important forms are presented in tables 12 to 40 inclusive. A detailed analysis of these results appears under the captions: "Field Observations on Severity of Rust Epidemics" and "Greenhouse and Laboratory Studies of Physiologic Forms."

Field Observations on Severity of Rust Epidemics

Previous to 1922 the rust estimates at some of the uniform nurseries were made by others than the writer. Thereafter, to obviate errors in the rust estimates, incident to differences of a personal equation, the writer whenever possible inspected all the nurseries himself, and wherever feasible took the rust readings together with the person in charge of the experiment. The scale (Fig. 2) used in the stem rust investigations made by the Office

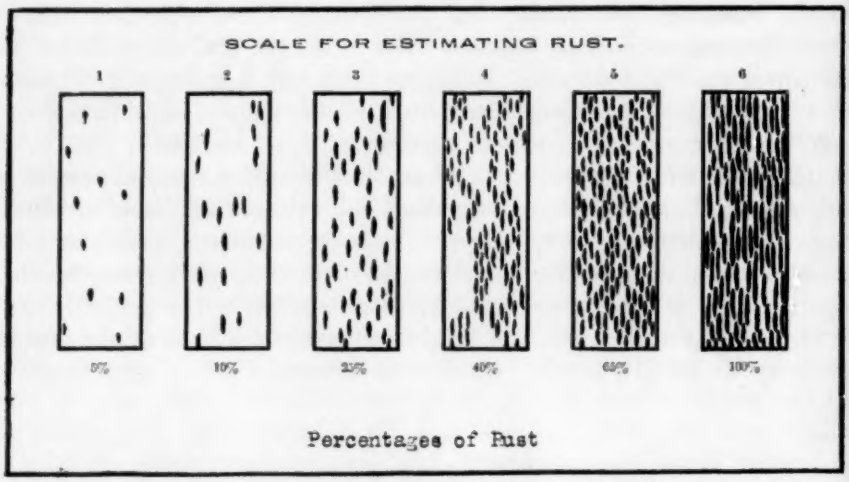


FIG. 2. Scale for estimating percentage of stem rust. The shaded spots represent rust, and the figures represent approximately the rust percentages computed on the basis of the maximum amount of surface covered by rust as shown in No. 6, which represents 37 per cent of surface covered with rust pustules and is arbitrarily selected as 100 per cent. Other percentages are based on No. 6. (From Office of Cereal Crops Diseases, United States Department of Agriculture).

of Cereal Crops and Diseases, United States Department of Agriculture, was used in estimating the percentage of rust on the varieties in the uniform nurseries. The rust estimates, as a rule, were made just before the plants ripened. However, the rust notes sometimes were taken while some of the varieties were still quite green, whereas in other cases a number of the varieties were dead ripe at the time the rust estimates were made. For obvious reasons this could not always be remedied. Whenever a variety was not grown at all of the stations, or the yearly average was not comparable with the other varieties, the fact is noted in footnotes to the tables. The percentage of stem rust infection of each variety of wheat and emmer at each uniform nursery, and the average infection of each variety for each year, are shown in tables 3 to 7 inclusive. Following the presentation of the data by years, weighted average infections for all varieties, during the entire five-year period, are given in table 8; these are then compared with the standard variety (Marquis, C. I. 3641) for the identical period of nursery years.

Rust Situation in 1919.

A heavy stem rust epidemic developed in the spring wheat region in 1919, but at St. Paul, Minn., only a trace of rust developed on all the durum varieties except Arnautka (C. I. 4064). Of the common varieties, Kota only was entirely rust free, whereas Prelude matured very early and obviously escaped the rust attack (see table 3). The identification of the physiologic forms which were responsible for the St. Paul epidemic might explain the seemingly peculiar behavior of the durums there. As will be seen from table 9, forms 3 and 12 were isolated from the St. Paul nursery in 1919. Stakman and Levine (30) have shown that Kubanka (C. I. 2094), Arnautka (C. I. 4072 and C. I. 6236), and Mindum (C. I. 5296) are all extremely resistant to form 3. The action of form 12 on the differential varieties of *Triticum spp.* is identical to that of form 3 in every respect except one—form 12 attacks Arnautka (C. I. 4072) very heavily. But Arnautka (C. I. 4064) has been found to react to the physiologic forms of *P. graminis tritici* in exactly the same manner as does Arnautka (C. I. 4072). This evidently accounts for the 65 per cent infection on Arnautka (C. I. 4064) and for the absence of infection on Arnautka (C. I. 6236), Mindum (C. I. 5296), and the three Kubanka strains. The few rusted individuals among the last named varieties evidently were "rogues."

Owing to severe drought and excessive heat at Dickinson, N. Dak., only a trace of stem rust could be found in the uniform nursery there. This was confined to three varieties: Arnautka (C. I. 6236), Mindum (C. I. 5296), and the Kubanka × Haynes hybrid (C. I. 4788).

TABLE 3.—*Percentage of stem rust on 20 varieties of spring wheat and emmer grown in uniform nurseries at 13 experiment stations in the United States in 1919*

[T = Trace]

Experiment stations	Estimated percentage of infection on																				
	Durum wheat									Hard red spring wheat									Emmer	
	Kubanka 1440	Kubanka 2094	Kubanka 4063	Arnautka 4064	Arnautka 6236	Mindum 5296	Acme 5284	Monad 3320	Pentad 3322	Haynes 2874	Marquis 3641	Power 3697	Ruby 6047	Preston 3081	Kota 5878	Prelude 4323	Kubanka × Haynes 4788	Kubanka × Preston 4789	Vernal 3686	Khapli 4013
Prairie (subhumid):																				
St. Paul, Minn.	[a]T	T	[a]T	65	[a]T	[a]T	T	[b]5	0	50	40	60	25	80	0	T	30	30	0	T
Fargo, N. Dak.	15	15	40	60	40	25	10	10	0	100	100	100	..	100	10	..	100	100	0	..
Brookings, S. Dak. ..	40	25	65	65	65	[c]55	0	0	0	100	85	100	100	95	5	100	100	100	0	0
Lincoln, Nebr.	15	5	65	50	25	5	2	3	T	100	85	90	65	90	[c]5	65	50	40	T	0
Ames, Iowa	9	T	7	20	20	6	3	3	T	75	75	65	35	65	T	5	40	20	T	0
Manhattan, Kans. ...	25	15	[d]..	30	40	25	T	5	5	90	70	80	[d]..	90	T	[d]..	60	70	T	[d]..
Great Plains (semi-arid):																				
Mandan, N. Dak. ...	[a]7	[a]3	[a]10	15	20	15	7	5	T	40	25	37	15	43	T	10	20	15	T	0
Dickinson, N. Dak. ..	0	0	0	0	T	T	0	0	0	0	0	0	0	0	0	0	T	0	0	0
Highmore, S. Dak. ..	25	65	65	65	80	25	5	5	0	100	70	95	20	90	T	15	40	25	1	1
Newell, S. Dak.	5	5	5	5	[b]25	5	[b]20	5	5	40	50	40	65	40	5	25	50	65	2	0
Archer, Wyo.	15	25	33	40	50	65	10	10	5	65	65	65	10	65	10	5	35	50	[b]25	5
Akron, Colo.	10	8	10	8	8	2	5	T	0	35	15	15	20	25	T	15	10	10	T	T
Amarillo, Texas	10	2	10	15	10	2	T	1	0	65	65	55	70	70	1	60	40	25	0	0
Average	14	13	[e]26	34	30	18	5	4	1	66	57	62	[f]39	66	3	[f]27	44	42	[b]2	[f]1

[a] Few but normal pustules.
[b] Mostly leaf-rust infection.
[c] Glumes and awns rusted.
[d] Harvested before rust notes were taken.
[e] Average of only 12 nurseries.
[f] Average of only 11 nurseries.

TABLE 4.—*Percentage of stem rust on 20 varieties of spring wheat and emmer grown in uniform nurseries at 16 experiment stations in the United States and Canada in 1920*

[T = Trace]

Experiment stations	Estimated percentage of infection on																			
	Durum wheat									Hard red spring wheat									Emmer	
	Kubanka 1440	Kubanka 2094	Kubanka 4063	Arnautka 4064	Arnautka 6236	Mindum 5296	Acme 5284	Monad 3320	Pentad 3322	Haynes 2874	Marquis 3641	Power 3697	Ruby 6047	Preston 3081	Kota 5878	Prelude 4323	Kubanka × Haynes 4788	Kubanka × Preston 4789	Vernal 3686	Khapli 4013
UNITED STATES																				
Prairie (subhumid):																				
St. Paul, Minn.[a]	95	100	95	95	95	95	25	25	30	100	100	100	85	100	40	95	95	100	15	5
Fargo, N. Dak.	15	15	15	40	40	25	10	0	0	100	65	100	40	100	10	40	100	100	0	0
Lincoln, Nebr.	5	10	5	5	5	5	4	4	4	33	[b]23	25	40	33	4	40	5	4	2	0
Great Plains (semiarid):																				
Mandan, N. Dak.	15	15	20	25	20	15	1	1	0	80	65	65	35	75	T	25	40	40	0	0
Dickinson, N. Dak.	10	6	7	14	8	7	3	5	1	22	16	17	15	20	1	19	17	13	T	T
Highmore, S. Dak.	5	5	5	5	5	5	T	T	T	40	25	20	10	40	5	10	40	40	T	T
Archer, Wyo.	25	25	25	50	50	25	5	5	5	50	40	50	50	50	25	40	25	40	0	0
Akron, Colo.	45	35	40	40	35	28	10	15	1	65	50	60	35	65	15	40	35	35	T	0
CANADA																				
Morden, Manitoba	25	25	30	35	35	35	7	7	1	50	50	50	50	65	40	50	40	50	2	1
Winnipeg, Manitoba	40	40	40	50	50	50	25	25	3	65	50	50	65	75	40	55	55	65	2	1
Brandon, Manitoba	40	50	40	50	[c]50	50	30	25	3	65	50	50	65	65	50	65	50	65	3	1
Indian Head, Saskatchewan	40	35	40	35	[c]40	35	25	25	3	55	50	65	65	65	35	55	65	65	1	1
Saskatoon, Saskatchewan ..	30	[d]30	30	30	[c]30	10	7	7	3	40	25	40	[b]40	35	1	35	40	35	0	1
Rosthern, Saskatchewan ...	35	40	45	40	35	10	7	7	1	75	25	40	35	35	3	35	50	40	1	1
Scott, Saskatchewan	2	2	3	1	1	0	0	1	0	15	10	8	15	20	1	20	8	8	1	1
Edmonton, Alberta	8	10	10	10	10	2	1	1	0	25	15	15	8	25	1	8	8	8	0	1
Average	27	28	28	33	32	25	10	10	3	55	41	47	41	54	17	40	42	44	2	1

[a] Nursery inoculated with spores of several physiologic forms found in Minnesota.
[b] Not grown; percentage of rust estimated from Power (C. I. No. 3697).
[c] Not grown; percentage of rust estimated from Arnautka (C. I. 4064).
[d] Not grown; percentage of rust estimated from Kubanka (C. I. 1440).

The agreement between the reaction of the varieties in the field and the greenhouse usually was fairly close. However, Acme, Monad, Pentad, and Kota constituted an exception to this rule. The resistance of these varieties in the field was striking, although the rust forms isolated from the nurseries readily attacked these varieties in the greenhouse. Otherwise, all varieties reacted the same in the field as they did in the greenhouse to cultures of the physiologic forms isolated from the plots in which they were grown.

It will be observed from tables 9 and 11 that seven different physiologic forms were isolated from eight of the 13 nurseries grown in 1919. At least two physiologic forms were responsible that year for the epidemics at Brookings, S. Dak. (forms 3 and 5); Fargo, N. Dak. (forms 3 and 22); and St. Paul, Minn. (forms 3 and 12). It will be noted further that form 3 appeared at all of these stations. This form also was found at Ames, Iowa, and thus was the most common physiologic form of *P. graminis tritici* in the spring-wheat region in 1919. Form 17 was found at but two stations: Akron, Colo., and Mandan, N. Dak. The other five forms were obtained from a single station each.

Rust Situation in 1920.

In 1920 there was another epidemic of stem rust. Acme, Monad, Pentad, and Kota rusted much more severely than in the previous year. It will be seen from table 4 that the highest percentage of infection on Pentad was found at St. Paul, namely, 30 per cent. At Brandon, Manitoba, 50 per cent infection was recorded on Kota, 30 per cent on Acme, and 25 per cent on Monad. At St. Paul, the rust infection on Kota was 40 per cent, whereas in the previous year Kota was totally free from rust. A difference in the weather conditions at the critical period apparently was responsible for the difference in the reaction of this variety to the rust attack. Physiologic forms virulent on Kota in the greenhouse were used in creating the rust epidemics at St. Paul in both years. The forms isolated in both years infected Kota heavily in the greenhouse.

Vernal was practically free from rust in 1920 at all stations except at St. Paul, where a virulent form was used for producing the epidemic. Professor Fraser reported that Vernal rusted heavily at Saskatoon, Sask., in 1919. But form 9, which attacks Vernal normally, was prevalent there that year, whereas in 1920 this form was late in appearing.

Form 17 led the frequency list in 1920, having appeared at five experiment stations. Form 3 followed as a close second with an invasion of four localities. In general, the 1920 epidemic in the uniform rust nurseries seems to have been caused by practically the same physiologic forms as in

1919 (table 9). Eight forms were isolated from 10 of the 16 stations in the United States and Canada (table 11).

Rust Situation in 1921.

In general, the stem rust epidemic in the uniform nurseries was somewhat milder in 1921 than in the two previous years. Table 5 shows that in the agronomy nursery at St. Paul only a trace of rust developed on a few of the durum varieties and only moderate infection on most of the hard red spring wheats. The plants matured early and evidently escaped the rust attack. A similar situation prevailed at Morris, Minn. At Golden Valley, Minn., and at Mandan and Dickinson, N. Dak., there was a very weak rust infection even on the most susceptible varieties. Only a trace of rust was present at Akron, Colo., where the weather conditions during the growing season were particularly unfavorable for the development of stem rust. However, in Manitoba and in most of Saskatchewan stem rust was quite prevalent; but at Scott, Sask., and in the nurseries in Alberta there was almost none.

Collections of rust from 16 of the 24 nurseries in the United States and Canada were cultured and identified in the greenhouses at University Farm, St. Paul. From the pathology nursery at St. Paul, where several physiologic forms were used to induce an artificial epidemic and where seven collections were made from different varieties and crosses of wheat, six forms were isolated. These were as follows: *P. graminis tritici* forms 1, 17, 18, 29, 30, and 36, all of which, except 36, had been used for the artificial inoculation. Two physiologic forms were found at each of the following nurseries: Fargo, N. Dak. (forms 21 and 29), Edgeley, N. Dak. (forms 9 and 37), Brandon, Man. (forms 9 and 29), Edmonton, Alta. (forms 9 and 17), Rosthern, Sask. (forms 29 and 32), and Winnipeg, Man. (forms 17 and 32). Only one form was isolated from each of the following places: Crookston, Minn.; Duluth, Minn.; Brookings, S. Dak.; Madison, Wis.; Ames, Iowa; Langdon, N. Dak.; Morden, Man.; and Saskatoon, Sask.; namely, 9, 21, 17, 37, 30, 21, 29, and 24, respectively.

It is possible that more forms than those isolated were actually responsible for the rust infection at the various stations in 1921. This probably accounts for some of the discrepancies in the behavior of the varieties in certain nurseries and the reaction of the differential hosts in the greenhouse toward the physiologic forms obtained from them. On the whole, however, there was a general agreement between the field observations and the results of inoculations in the greenhouse.

Rust Situation in 1922.

The infection in the nurseries was heavier in 1922 than in any of the other years during the course of the investigation (See table 6).

TABLE 5.—*Percentage of stem rust on 24 varieties of spring wheat and emmer grown in uniform nurseries at 24 experiment stations in the United States and Canada in 1921*

[T = Trace]

Experiment stations	Estimated percentage of infection on																							
	Durum wheat												Hard red spring wheat									Club wheat	Emmer	
	Kubanka 1440	Kubanka 2094	Kubanka 4063	Arnautka 1493	Arnautka 4064	Arnautka 6236	Mindum 5296	Acme 5284	Monad 3320	Pentad 3322	Kahla 5529	Peliss 1584	Haynes 2874	Marquis 3641	Power 3697	Ruby 6047	Kitchener 4800	Red Bobs 6255	Preston 3081	Kota 5878	Prelude 4323	Little Club 4066	Vernal 3686	Khapli 4013
UNITED STATES																								
Prairie (subhumid):																								
St. Paul, Minn.—																								
Pathology nursery	[a]T	[a]T	25	30	40	[a]T	[a]T	0	0	0	[b]25	[b]65	50	40	55	30	80	40	45	T	40	40	0	0
Agronomy nursery	0	0	0	0	0	0	[a]T	0	0	0	T	T	T	T	25	T	20	[b]15	[b]20	0	10	[b]25	0	0
Crookston, Minn.	50	50	60	70	65	45	25	2	2	2	60	55	85	90	85	60	95	98	90	2	15	60	2	0
Morris, Minn.	2	2	2	5	5	5	T	T	T	2	T	2	75	40	15	3	50	40	40	15	10	60	2	T
Golden Valley, Minn.	..	0	T	2	T	..	0	T	0	0	0	..	5	10	..	5	..	..	..	0	..	5	0	0
Duluth, Minn.	..	15	..	55	..	..	10	T	T	T	..	..	50	55	..	50	..	60	55	T	..	..	0	..
Madison, Wis.	25	20	25	30	30	28	28	T	2	2	60	70	90	85	70	70	80	75	80	T	[c]60	[c]70	5	0
Fargo, N. Dak.	45	40	45	60	75	75	80	d15	d10	d10	95	75	95	90	100	[e]35	85	65	95	5	[e]40	[e]100	0	0
Brookings, S. Dak.	25	20	28	33	40	40	35	d12	d15	d12	50	40	55	50	55	30	50	35	40	5	15	[e]30	0	0
Ames, Iowa	20	10	15	15	10	18	18	0	0	0	20	20	40	28	30	25	40	35	35	5	20	50	0	0
Great Plains (semiarid):																								
Langdon, N. Dak.	20	7	18	20	18	18	18	2	3	2	35	50	25	25	25	25	40	25	25	1	[f]..	35	0	[f]..
Edgeley, N. Dak.	45	25	45	32	40	40	35	5	3	0	95	70	70	85	75	55	80	65	75	T	65	85	0	0
Mandan, N. Dak.	5	3	2	5	3	5	1	T	0	0	3	T	10	8	6	1	15	3	8	0	0	25	0	0
Dickinson, N. Dak.	T	T	2	2	2	2	5	5	T	T	10	5	12	5	5	T	12	2	3	T	T	5	T	0
Akron, Colo.	0	0	0	0	0	0	0	0	0	0	0	0	0	T	0	0	0	0	0	0	0	0	0	0
CANADA																								
Morden, Manitoba	60	50	70	70	75	75	75	30	25	3	55	30	80	65	75	[f]..	65	[f]..	80	8	[f]..	40	0	0
Winnipeg, Manitoba	40	35	45	40	55	40	35	4	3	0	40	35	60	90	70	90	90	85	85	3	70	50	0	0
Brandon, Manitoba	50	60	45	35	40	45	35	3	5	1	30	20	50	70	40	50	45	35	40	5	40	10	T	0
Indian Head, Saskatchewan	3	2	20	15	10	20	5	0	0	0	20	20	80	45	10	60	45	40	35	55	60	5	0	0
Saskatoon, Saskatchewan	5	10	20	8	25	20	5	1	T	T	10	10	5	60	30	50	70	50	50	0	40	30	0	0
Rosthern, Saskatchewan	15	15	25	30	40	25	10	1	1	0	30	20	80	85	80	75	75	60	75	5	50	85	0	0
Scott, Saskatchewan	0	0	0	0	T	0	0	0	0	0	0	0	0	0	T	0	T	0	T	0	0	0	0	0
Vermilion, Alberta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	T	0	0	0	0	0	0	0
Edmonton, Alberta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lacombe, Alberta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	[g]18	15	[h]21	22	[h]24	[g]22	17	3	3	1	[h]27	[g]26	41	41	[g]37	[h]30	[g]45	[g]36	[h]41	2	[i]25	[h]34	T	[g]0

[a] Few but normal pustules.
[b] Infection not uniform.
[c] Many plants destroyed by gophers and sparrows.
[d] Mostly on immature plants.
[e] Plants dead ripe.
[f] Destroyed by gophers and sparrows.
[g] Average of only 23 nurseries.
[h] Average of only 24 nurseries.
[i] Average of only 21 nurseries.

b Infection not uniform.
c Many plants destroyed by gophers and sparrows.
e Plants dead ripe.
f Destroyed by gophers and sparrows.
i Average of only 21 nurseries.

TABLE 6.—*Percentage of stem rust on 22 varieties of spring wheat and emmer grown in uniform nurseries at 19 experiment stations in the United States in 1922*
[T = Trace]

Experiment stations	Estimated percentage of infection on																					
	Durum wheat										Hard red spring wheat									Club wheat	Emmer	
	Kubanka 1440	Kubanka 4063	Arnautka 1493	Arnautka 4064	Mindum 5296	Acme 5284	Monad 3320	Pentad 3322	Kahla 5529	Peliss 1584	Haynes 2874	Marquis 3641	Power 3697	Ruby 6047	Kitchener 4800	Red Bobs 6255	Preston 3081	Kota 5578	Prelude 4323	Little Club 4066	Vernal 3686	Khapli 4013
Prairie (subhumid):																						
St. Paul, Minn.																						
Pathology nursery	45	45	40	40	50	T	T	0	70	50	80	80	85	85	75	80	85	[a]2	35	65	T	0
Agronomy nursery	25	25	25	25	25	T	T	T	50	40	60	50	60	50	50	50	65	T	10	45	0	0
Crookston, Minn.	65	65	65	65	55	10	10	10	75	75	90	90	90	90	90	90	90	5	15	90	0	0
Morris, Minn.	25	20	20	25	18	2	7	12	35	25	60	30	50	45	50	55	75	15	15	85	T	0
Waseca, Minn.	40	55	60	60	50	1	T	5	85	75	95	95	95	75	80	75	75	8	25	75	T	T
Coon Creek, Minn.	..	..	..	25	15	0	T	T	3	20	25	25	..	..	25	30	40	5	7	60	0	0
Duluth, Minn.	..	..	..	..	28	..	..	1	..	..	68	80	..	18	..	..	60	18	..	..	[a]3	..
Chatham, Mich.	40	60	40	12	45	T	0	0	60	25	15	45	25	50	25	35	20	0	25	8	0	0
Madison, Wis.	45	45	45	45	45	12	12	12	4	4	45	4	20	4	20	20	20	5	4	30	0	0
Fargo, N. Dak.	95	98	98	98	100	5	5	5	100	90	100	98	98	90	95	95	95	35	45	75	T	0
Brookings, S. Dak.	65	70	80	90	85	15	18	15	85	45	95	65	75	60	65	65	90	12	40	65	T	0
Lincoln, Nebr.	25	60	60	60	75	8	15	12	85	45	60	30	40	20	20	15	25	5	T	30	0	0
Ames, Iowa	35	30	15	12	12	0	0	0	30	20	35	35	30	25	35	35	45	T	T	[b]T	T	0
Great Plains (semiarid):																						
Langdon, N. Dak.	18	18	12	12	10	T	T	T	25	12	50	40	45	50	60	55	65	T	35	90	0	0
Edgeley, N. Dak.	20	25	20	25	25	2	T	T	20	18	35	45	40	20	35	30	25	T	5	35	0	0
Mandan, N. Dak.	25	25	35	45	25	5	7	10	25	15	75	40	75	30	40	40	70	15	3	95	T	0
Dickinson, N. Dak.	25	25	20	40	20	3	5	7	20	25	75	55	80	70	95	80	80	20	25	95	3	0
Redfield, S. Dak.	45	45	40	55	25	5	7	7	65	45	80	80	80	12	45	18	55	3	3	35	0	0
Archer, Wyo.[c]	5	0	0	0	0	0	0	0	0	T	0	0	T	3	T	1	T	1	1	5	T	0
Akron, Colo.	T	T	T	T	T	T	T	0	T	1	2	T	5	8	12	12	15	7	T	25	0	0
Average	[d]36	[d]39	[d]38	[e]39	35	[e]4	[e]5	5	[e]44	[e]33	57	49	[d]55	[e]42	[e]48	[e]46	55	8	[e]15	[e]53	T	[e]0

a Pustules minute.
b Few but normal pustules.
c About a month later the rust on Kubanka 1440 developed to be 15 per cent, on Power to 30 per cent, and on Little Club to 25 per cent.
d Average of only 18 nurseries.
e Average of only 19 nurseries.

TABLE 7.—*Percentage of stem rust on 24 varieties of spring wheat and emmer grown in uniform nurseries at 19 experiment stations in the United States in 1923*
[T = Trace]

Experiment stations	Estimated percentage of infection on																							
	Durum wheat												Hard red spring wheat									Club wheat	Emmer	
	Kubanka 1440	Kubanka 2094	Kubanka 4063	Arnautka 1493	Arnautka 4064	Arnautka 6236	Mindum 5296	Acme 5284	Monad 3320	Pentad 3322	Kahla 5529	Peliss 1584	Haynes 2874	Marquis 3641	Power 3697	Ruby 6047	Kitchener 4800	Red Bobs 6255	Preston 3081	Kota 5878	Prelude 4323	Little Club 4066	Vernal 3686	Khapli 4013
Prairie (subhumid):																								
St. Paul, Minn.—																								
Pathology nursery ..	15	12	15	12	15	12	8	T	1	T	18	18	25	30	35	35	45	40	45	2	35	45	T	0
Agronomy nursery ..	12	8	12	12	20	15	10	T	1	T	25	18	25	35	25	20	40	30	30	5	12	50	0	0
Crookston, Minn.	30	25	30	18	25	32	25	T	T	T	40	45	70	40	60	50	50	55	60	8	60	75	T	1
Morris, Minn.	30	15	15	25	30	25	20	1	5	5	30	30	95	90	95	90	90	90	95	40	50	90	0	0
Waseca, Minn.	20	10	12	15	15	18	10	T	0	T	15	5	35	35	45	30	70	50	50	1	15	70	0	0
Coon Creek, Minn.—																								
Sandy soil	5	8	8	10	10	10	8	3	2	T	10	10	25	25	25	15	20	18	25	T	10	25	0	0
Peat bog	20	20	25	35	30	45	40	T	T	0	20	20	90	95	95	98	95	95	98	15	95	85	0	0
Duluth, Minn.	35	40	45	45	50	50	40	T	T	T	65	25	65	80	90	45	50	40	60	10	60	50	T	2
Chatham, Mich.	20	20	25	20	25	35	30	T	T	T	35	45	30	25	20	50	45	60	40	12	50	15	0	0
Madison, Wis.	18	5	12	15	10	18	15	0	T	0	25	18	40	45	50	65	75	75	70	8	60	70	0	0
Fargo, N. Dak.	25	30	35	45	45	45	45	T	T	T	25	45	75	70	80	65	75	75	80	35	30	35	0	T
Brookings, S. Dak.	35	45	50	40	40	35	40	20	15	18	40	40	70	70	70	55	60	60	75	60	45	75	T	1
Lincoln, Nebr.	12	5	7	5	8	8	5	T	0	0	8	12	12	15	15	10	15	8	10	T	3	12	0	0
Ames, Iowa	25	20	30	25	30	35	25	8	8	8	85	70	75	75	75	70	65	55	75	5	25	25	0	0
Great Plains (semiarid):																								
Langdon, N. Dak.	20	25	30	25	35	30	30	0	0	T	30	30	90	85	90	80	80	85	98	15	35	95	T	0
Edgeley, N. Dak.	17	22	25	25	30	35	20	T	2	T	50	40	90	80	85	70	75	80	85	5	65	80	0	T
Mandan, N. Dak.	12	12	10	15	20	18	18	T	T	T	25	25	40	30	50	40	40	45	55	15	15	55	0	0
Dickinson, N. Dak.	18	25	20	20	18	25	25	1	2	T	15	20	75	20	75	15	20	18	75	10	40	55	0	1
Redfield, S. Dak.	25	20	25	15	20	20	18	5	3	T	25	18	55	50	55	45	55	50	60	25	20	50	0	0
Archer, Wyo.	35	30	35	25	35	35	40	8	6	4	50	40	35	50	50	55	60	60	50	35	55	60	0	T
Akron, Colo.	30	30	35	30	25	25	20	10	10	8	50	30	40	40	45	35	45	45	50	20	25	50	0	0
Average	22	20	24	23	26	27	23	3	3	2	33	29	55	52	59	49	56	54	61	16	38	56	0	T

TABLE 8.—*Average percentage of stem rust infection on wheat varieties grown in uniform rust nurseries at 34 experiment stations in the United States and Canada during one or more of the five years, 1919 to 1923, inclusive, together with the coefficient of infection, i.e., in comparison with the percentage of infection on Marquis during the corresponding period*

Class, variety, and C. I. number	Total number of nursery years	Percentage of stem rust infection										
		Annual averages					Five-year averages					
							Individual varieties			Entire class		
		1919	1920	1921	1922	1923	Weighted average	Marquis during identical period of nursery years	Coefficient of infection (per cent of Marquis)	Weighted average	Marquis during identical period of nursery years	Coefficient of infection (per cent of Marquis)
Durum (*Triticum durum*)	..	...	...	...	...	...	...	...	.....	19.94	47.08	42.35
Kubanka 1440	91	13.5	27.2	17.8	35.7	21.9	23.3	47.6	48.95			
Kubanka 2094	75	12.9	27.7	14.6	...	20.3	18.7	46.9	39.87			
Kubanka 4063	91	25.8	28.1	20.5	39.5	23.9	27.1	47.0	57.66			
Arnautka 1493	64	...	...	22.3	37.5	22.7	26.7	46.8	57.05			
Arnautka 4064	93	33.7	32.8	23.9	38.6	25.5	30.2	46.9	64.38			
Arnautka 6236	73	29.5	31.8	21.8	...	27.2	26.9	47.3	56.86			
Mindum 5296	95	17.7	24.8	16.8	35.4	23.4	23.6	47.4	49.79			
Acme 5284	94	4.8	10.0	3.2	3.6	2.7	4.6	47.1	9.76			
Monad 3320	94	4.0	9.6	2.8	4.5	2.6	4.4	47.1	9.34			
Pentad 3322	95	1.2	3.4	1.4	4.8	2.0	2.6	47.4	5.48			
Kahla 5529	64	...	...	26.6	44.1	32.7	33.8	46.3	73.00			
Peliss 1584	63	...	...	25.5	33.2	28.8	28.9	46.9	61.62			
Common (*Triticum vulgare*)	..	...	...	...	...	...	...	...	.....	42.96	47.24	90.94
Haynes 2874	95	66.2	55.0	40.7	57.3	55.1	53.3	47.4	112.45			
Marquis 3641	95	57.3	41.2	41.0	49.4	51.7	47.4	47.4	100.00			
Power 3697	91	61.7	47.2	37.0	55.2	58.6	50.9	47.6	106.94			
Ruby 6047	91	38.6	40.8	29.8	42.4	49.4	40.0	47.0	85.10			
Kitchener 4800	63	...	...	45.1	48.3	55.7	49.6	46.9	105.75			
Red Bobs 6255	63	...	...	36.0	46.4	54.0	45.1	46.7	96.57			
Preston 3081	94	65.6	54.3	40.7	54.8	61.2	54.0	47.8	112.97			
Kota 5878	95	2.8	16.9	2.4	7.8	15.5	8.9	47.4	18.78			
Prelude 4323	88	27.3	39.5	25.5	15.4	38.3	29.1	46.6	62.44			
Club (*Triticum compactum*) ...	..	...	...	...	...	...	...	...	.....	46.68	46.31	100.78
Little Club 4066	64	...	...	33.8	53.1	55.6	46.7	46.3	100.86			
Emmer (*Triticum dicoccum*) ...	..	...	...	...	...	...	...	...	.....	0.51	46.90	1.09
Vernal 3686	95	2.2	1.7	0.4	0.3	0.0	0.8	47.4	1.69			
Khapli 4013	90	0.5	0.8	0.0	0.0	0.2	0.3	46.4	0.64			
Average annual epidemic		26.0	27.4	21.9	32.0	30.4						

The varieties which are resistant in the field, however, were less severely rusted than in 1920. The highest percentage of infection on the three most resistant durum varieties, Acme, Monad and Pentad, occurred at Brookings, S. Dak., where from 15 to 18 per cent of infection was recorded. The highest degree of infection on Kota was found in the uniform rust nursery at Fargo, N. Dak., where there was an infection of 35 per cent under conditions of almost complete lodging. In the same nursery the infection on Marquis was as high as 98 per cent. In plot experiments at the same station, where there was no lodging and where the plants were fully mature, Kota had only 10 per cent of stem rust while the infection on Marquis was 80 per cent.

Rust specimens were obtained from each nursery and the material was cultured in the greenhouse at St. Paul for the purpose of identification. The rust responsible for the infection at Chatham, Mich., Madison, Wis., Waseca and Crookston, Minn., Edgeley, N. Dak., Brookings, S. Dak., Lincoln, Nebr., and Akron, Colo., was form 21. At Coon Creek, Minn., and Redfield, S. Dak., forms 21 and 17 were present. From each of the collections made at Duluth and Morris, Minn., and at Ames, Iowa, form 17 alone was isolated. Form 11 was responsible for the epidemic at Langdon, N. Dak. The rust at Fargo, N. Dak., consisted of forms 17 and 9; at St. Paul, Minn., both form 9 and form 32 were found; whereas at Archer, Wyo., form 9 was found in conjunction with form 34, this being the first time form 34 was found in the United States. Two forms were isolated from the Mandan, N. Dak., nursery; *viz.*, form 36 and a form which acted unlike any of those previously described and which was therefore designated as form 38.

It is interesting to note that forms 17, 21, and 34 are absolutely identical with respect to their parasitic behavior on the different varieties grown in the uniform rust nurseries. Form 9 differs from these only by its ability to infect Vernal normally in the greenhouse, which the other forms do not have. Form 11 acts like form 17 but can also attack Kanred (C. I. 5146), while form 17 can not. Form 32 is essentially the same as form 11, except that the infection it produces on the durums is of the "x" type instead of normal. Form 38 behaves in every respect like form 32 except that it can not infect Marquis normally.

Rust Situation in 1923.

In general, the wheat rust infection in the uniform rust nurseries in 1923 agrees fairly closely with the 5-year weighted average, as may be seen from table 8. There was a rather unusually heavy stem rust infection that year on Kota at some of the nurseries in the United States, particularly at Brookings, S. Dak. (60 per cent.); Morris, Minn. (40 per cent); Fargo,

N. Dak. (35 per cent), etc. In 1920 the percentage of infection on Kota was as high as 50 per cent at Brandon, Manitoba, and 40 per cent at Morden and Winnipeg, Man. It will be interesting to note that the average for Kota in 1923 is almost the same as that in 1920, *i.e.*, 16 and 17 per cent, respectively.

Form 11 was responsible for the rust infection in seven nurseries, *viz.*, St. Paul (pathology and agronomy nurseries), Crookston, Fargo, Ames, Langdon and Archer; form 21 was dominant in six nurseries, namely, Morris, Coon Creek (sandy soil), Brookings, Lincoln, Edgeley and Akron; form 32 predominated in the following five nurseries: Coon Creek (peat bog), Duluth, Chatham, Dickinson, and Redfield; form 29 appeared in two nurseries, Waseca and Madison; whereas form 17 was obtained only from Mandan. The rust estimates for each variety at each nursery are given in table 7.

From the results presented in tables 3 to 7 inclusive, and from the accompanying discussions it can be seen that some varieties rusted heavily at most of the stations each year. Nearly all the hard red spring wheat varieties grown were susceptible to the prevailing physiologic forms. Some varieties of durum were considerably more susceptible than others; but, in general, as shown in table 8, all of the durum varieties as a class had a lower percentage of infection than either Marquis or the entire class of common wheats (approximately 20 per cent for the durums as against 43 per cent $\pm$ for the common varieties). Pentad, Monad, and Acme in the order named were the most resistant durum varieties under field conditions. Kota was much more resistant to stem rust attack during five years as a whole than was Marquis, the data showing about 9 per cent for the former, as compared with over 47 per cent for the latter. Marquis escaped stem rust infection slightly better than either Kitchener, Power Fife, Haynes Bluestem, or Preston, in the order named. However, both Prelude and Ruby fared better than Marquis. The two varieties of spring emmer (Vernal and Khapli) were virtually immune from stem rust in the field, although, as recorded in table 11, during the 5-year period, two physiologic forms which infected Vernal very readily under greenhouse conditions (forms 9 and 30) were isolated 11 different times. Little Club was completely susceptible throughout.

Greenhouse and Laboratory Studies of Physiologic Forms

Rust specimens were collected each year at some or all of the uniform rust nurseries and sent to St. Paul for identification. During the period under review 78 collections were cultured in the greenhouses at University Farm and the identity of the physiologic forms isolated was established.

TABLE 9.—*Occurrence of physiologic forms of Puccinia graminis tritici during the 5 years, 1919–1923, inclusive, at different uniform rust nurseries in the United States and Canada*

Experiment stations	Physiologic forms found in:					Number of forms isolated from each station
	1919	1920	1921	1922	1923	
United States						
Akron, Colo.	17			21	21	2
Ames, Iowa	3		30	17	11	4
Archer, Wyo.	11			9, 34	11	3
Brookings, S. Dak.	3, 5		17	21	21	4
Chatham, Mich.				21	32	2
Coon Creek, Minn.				17, 21	21, 32	3
Crookston, Minn.			9	21	11	3
Dickinson, N. Dak.				9	32	2
Duluth, Minn.			21	17	32	3
Edgeley, N. Dak.			9, 37	21	21	3
Fargo, N. Dak.	3, 22		21, 29	9, 17	11	7
Langdon, N. Dak.			21	11	11	2
Lincoln, Nebr.	13	11, 13		21	21	3
Madison, Wis.			37	21	29	3
Mandan, N. Dak.	17	17		36, 38	17	3
Morris, Minn.				17	21	2
Redfield, S. Dak.				17, 21	32	3
St. Paul, Minn.	3, 12	3[a]	1, 17, 18, 29, 30, 36	9, 32	11[b]	11
Waseca, Minn.				21	29	2
Canada						
Brandon, Man.		3, 29	9, 29			3
Edmonton, Alta.		29	9, 17			3
Indian Head, Sask.		12, 17	29			3
Morden, Man.		3, 32	29			3
Rosthern, Sask.		3, 9, 17	29, 32			5
Saskatoon, Sask.		17	24			2
Winnipeg, Man.		17	17, 32			2
Most prevalent forms in any one year, in their order of prevalence.	3, 17	17, 3, 29	29, 9, 17, 21	21, 17, 9	11, 21, 32	

[a] Nursery inoculated with several physiologic forms, but form 3 was seemingly dominating.

[b] Culture badly mixed, but form 11 apparently predominated.

Identity and Nature of Physiologic Forms Isolated.

The identity of the rusts collected was determined by the method described by Stakman and Levine (30). The various types of infection produced by different physiologic forms of *P. graminis tritici* on seedling plants are illustrated in Plate I. The forms isolated from a given nursery in a given year are listed in table 9. Most of the collections made, namely, 57, consisted of a single form each; 20 contained two forms each; while three different forms were isolated from one individual collection. The classes of host reaction and the corresponding types of rust infection, resulting from inoculation of seedling wheat plants with spores of *Puccinia graminis tritici*, are described below.

Different types of infection produced by physiologic forms of *Puccinia graminis tritici* on seedlings of different varieties of wheat.

CLASS "R" (Varieties resistant) is indicated by infection types, 0, 1, and 2, and their plus and minus fluctuations.

Type (0)—Host practically immune—No uredinia are developed, but sharply defined hypersensitive flecks or necrotic lesions are usually present;

Type (1)—Host extremely resistant.—Infection very light; uredinia minute and scattered and surrounded by very sharply defined, continuous necrotic areas;

Type (2)—Host moderately resistant.—Infection light; uredinia isolated and small to medium in size; hypersensitive areas in the form of necrotic halos or circles; pustules usually in green, but slightly chlorotic, islands.

CLASS "S" (Varieties susceptible) is indicated by infection types 3 and 4, and their plus and minus fluctuations.

Type (3)—Host relatively susceptible.—Infection moderate; uredinia midsized with slight tendency to coalesce; true hypersensitiveness absent, but light chlorotic areas usually present, especially under unfavorable cultural conditions.

Type (4)—Host completely susceptible.—Infection normal and heavy; uredinia large and generally confluent; hypersensitiveness normally absent, but chlorosis may be present when cultural conditions are unfavorable.

CLASS "I" (Reaction indeterminate) is indicated by infection type X with the accompanying plus and minus fluctuations.

Type (X)—Host intermediately susceptible.—Infection of a heterogeneous nature; uredinia very variable, apparently in-

cluding all types and degrees of infection, often on the same blade; no mechanical separation seems to be possible, since, on reinoculation, spores from small uredinia may produce large ones, and *vice versa*. In general, the infection is ill defined.

The nature of the parasitic behavior of the different physiologic forms isolated is shown in table 10. It will be seen from this table that all these forms, except form 38, which was found together with form 36 at Mandan, N. Dak., in 1922, attack Marquis very readily. It will be interesting to note, also, that in the greenhouse Kota is more or less susceptible to all of these forms except form 24, which was found at Saskatoon, Sask., in 1921. All of the hard red spring varieties tested in the nurseries, except Kota, reacted like Marquis to the different forms isolated, *i.e.*, they were susceptible to them and might therefore be considered as a group unit. The durums are different in this respect because they all reacted differently to

TABLE 10.—*Reaction of differential varieties of wheat to physiologic forms of stem rust isolated from different uniform rust nurseries in the United States and Canada during the 5 years, 1919–1923, inclusive*

Physiologic forms isolated	Mean reaction[a] of differential varieties											
	Club	Hard Red			Durum					Einkorn	Emmer	
	Little Club C. I. 4066	Marquis C. I. 3641	Kanred C. I. 5146	Kota C. I. 5878	Arnautka C. I. 4072	Mindum C. I. 5296	Arnautka C. I. 6236	Kubanka C. I. 2094	Acme C. I. 5284	Einkorn C. I. 2433	Vernal C. I. 3686	Khapli C. I. 4013
1.....	4	4–	0	3+	1=	1	1=	3+	3++	3	0;	1=
3.....	4	4–	4=	3+	1=	1=	1–	1+	3++	3+	1=	0;
5.....	4	4–	0;	3	4=	3++	3++	1++	3+	3	0;	0.
9.....	4	4–	0	3++	4–	4=	4=	4=	3++	3+	4=	1–
11.....	4–	4=	3++	3+	4=	4=	4=	3++	3++	3	1=	1=
12.....	4+	4–	4=	3+	4=	1	1++	1++	3++	3+	1=	0;
13.....	4	4–	3++	3++	4=	3++	3++	2–	3++	3	1	1=
17.....	4	4–	0.	3+	4=	4=	4=	3++	3++	3	1=	1=
18.....	4	4–	4=	3++	1	1=	1–	3++	3++	3	1–	1=
21.....	4	4	0	3++	4–	4–	4–	4=	3++	1=	0;	1=
22.....	4+	4+	4	3	1	4	4–	0.	3+	3	1–	0.
24.....	4	4=	0;	2=	4=	4=	4=	3++	3+	3	1=	0;
29.....	4	4–	0	3	X++	X	X+	X–	X+	3	1–	1–
30.....	4	4	0.	3++	X++	X±	X+	X	X+	3+	4=	1
32.....	4	4=	4=	3+	X+	X	X±	X	X+	3	1=	1–
34.....	4+	4–	4–	4=	4	4=	4=	4=	3++	1=	0;	1=
36.....	4	4	4–	3++	1=	1=	0;	X	3++	3	0;	1–
37.....	4	4–	0	3++	4=	4=	4=	X	3–	3	1=	1–
38.....	4	2=	4–	3++	X+	X±	X+	X++	X++	4–	1=	1+

[a] *Explanation of symbols:* O—Absolute immunity; 1—Extreme resistance; 2—Moderate resistance; 3—Moderate susceptibility; 4—Complete susceptibility; X—Heterogeneous reaction; (;)—Hypersensitive flecks; (.)—Necrotic lesions. Plus and minus signs indicate a slightly greater or less amount of rust than the nearest figure representing the infection type (30).

certain individual forms. Vernal emmer was susceptible in the greenhouse to two of the forms isolated, *viz.*, forms 9 and 30. Khapli and Little Club reacted uniformly to all of the physiologic forms, the former being extremely resistant and the latter completely susceptible to all of them.

Some of the forms isolated are quite virulent and others are very weak. Under favorable conditions, forms 11, 17, and 21 can attack very heavily all of the varieties tested in the uniform nurseries except Vernal and Khapli emmers. These forms are not identical, however, because they vary greatly in their parasitism on other varieties. They can be separated from each other on the basis of their action on Kanred (C. I. 5146) and Einkorn (C. I. 2433).

Forms 9 and 30 can infect Vernal (C. I. 3686) in the greenhouse. Form 30 differs from form 9 only in that its action on the durums is heterogeneous and it is therefore somewhat less virulent than form 9. A similar relationship exists between forms 32 and 11 and forms 29 and 17. Marquis is resistant to form 38, but in all other respects this form behaves just like form 32. Form 37 approaches form 17 more closely than does form 29, there being just one point of difference between the first two, namely, Kubanka (C. I. 2094) alone reacting indeterminately to form 37, whereas all the durum differentials react thus to form 29.

Forms 13, 22, 12, and 18 bear a certain relation to form 11. But form 13 differs from 11 in not being able to attack Kubanka (C. I. 2094) normally. Form 22 is one degree less virulent than form 13, Arnautka (C. I. 4072) and also Arnautka (C. I. 4064 and C. I. 1493) being resistant to it in addition to Kubanka (C. I. 2094). Form 12, although capable of producing heavy infection on Arnautka (C. I. 4072), can infect Arnautka (C. I. 6236), Mindum (C. I. 5296), and Kubanka (C. I. 2094) only with great difficulty. This order is slightly shifted in the case of form 18, to which both Arnautka strains, as well as Mindum, are highly resistant, but Kubanka is very susceptible. Form 36 is slightly less virulent than form 18, as it produces a heterogeneous type of infection on Kubanka (C. I. 2094). This variety is completely resistant to form 3, otherwise form 3 is identical with forms 36 and 18.

Form 5 is similar to form 17 and differs from form 17 only in that it can not normally infect Kubanka (C. I. 2094). Form 1, like form 17, is capable of producing heavy infection on Kubanka, but Mindum and the two strains of Arnautka are extremely resistant to it. In this respect it differs from form 17. Form 24 also is closely allied to form 17 and differs from it in just one particular: it can not attack Kota normally either in the field or greenhouse.

Prevalence and Distribution of Physiologic Forms Isolated

From 1919 to 1923, inclusive, 19 different forms of *P. graminis tritici* were isolated from the nurseries. It will be seen from table 11 and figure 3

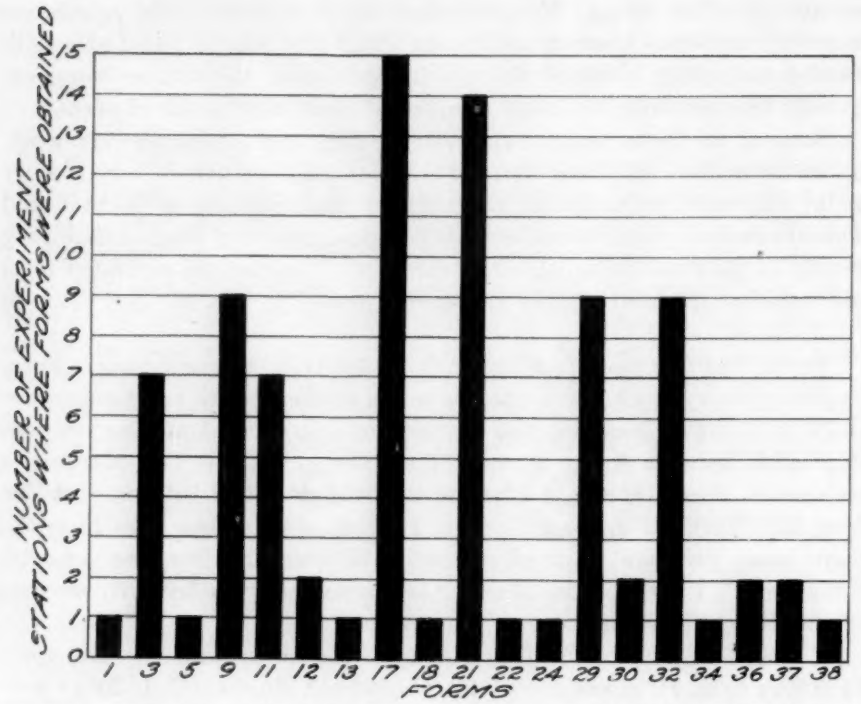


FIG. 3. Prevalence of physiologic forms of *Puccinia graminis tritici* isolated from uniform rust nurseries during the 5-year period, 1919–1923, inclusive.

that form 17 was isolated most frequently and from the greatest number of localities. Margaret Newton (20) found this form to be quite widely distributed also in Canada. It appeared to a greater or less extent in the uniform rust nurseries each year and was isolated from 15 different localities. Table 9 shows that form 17 occupied the second place in frequency of occurrence in 1919, form 3 being first. However, form 17 led the frequency list in 1920, but in 1921 it again dropped to the second place, which it shared with form 9. Form 29 headed the frequency list in 1921, was not found in the nurseries in 1922 and was at the bottom of the list in 1923. Form 21 was found in 14 different nurseries, but apparently was a factor in the rust epidemic only during the last three years of the experiment. In 1921 it was isolated from three localities, holding the third frequency position; in 1922 it appeared in 10 different places of the experimental area and was the first on the list; in 1923 it shared this position with form 11, having been found at six of the stations.

Forms 11 and 32 both were isolated in four different years, but during this period they were found only at seven and nine separate nurseries,

respectively. Forms 9 and 29 were found three different years, the former in 1920, 1921, and 1922; the latter in 1920, 1921, and 1923. Both appeared in nine different localities. Forms 3, 12, and 36 each were collected for two consecutive years, the first two forms in 1919 and 1920, the last in 1921 and 1922. Form 3 was found at seven different localities, whereas forms 12 and 36 each were found at only two localities. The remaining forms occurred only in individual years, and each of them, except forms 30 and 37, in only a single locality. Form 30 and form 37 both were found in 1921 and in two different nurseries, the first at Ames, Iowa, and St. Paul, Minn., the last at Edgeley, N. Dak., and Madison, Wis.

Too sweeping conclusions should not be drawn from the above discussion on distribution and prevalence of physiologic forms. It must be remembered that, after all, only a rather limited number of collections were made at these stations, yielding a comparatively small number of individual cultures. It should also be borne in mind that collections were not made each year from every nursery. Nevertheless, there seems to be fair evidence that certain forms occur more frequently than others and that some forms have a wider range of distribution than other forms. Sometimes the most frequently occurring forms are also the most widely distributed ones, and *vice versa*; but this is not necessarily always the case. Neither the prevalence of a physiologic form, nor its distribution, could be correlated with the degree of its virulence on the differential hosts.

Several factors affect the prevalence and distribution of physiologic forms of *P. graminis tritici*. It has been demonstrated (11, 38, 36, 15) that the parasitism of the different varieties of *P. graminis* is profoundly affected by resistant hosts. It is quite obvious, therefore, that resistant varieties of wheat, grown in a given region, impose a definite restraint on the occurrence of certain forms of *P. graminis tritici* in that region. It also has been shown (13, 6, 23) that the physiologic forms of stem rust differ: first, in the germinability of their spores in diverse temperature ranges; second, in their ability to develop in the host plant under different environmental conditions; and, third, in their capacity to hibernate in the host tissue. Consequently, it is very likely that the difference in the climatic conditions in the various parts of the country plays no small part in the distribution of these forms. In addition to this, there also are the prevailing winds and the upper air currents, and possibly the fortuitous mutational origin of physiologic forms, which must be taken into consideration. Then there also is the possibility that the different stem rust forms originate through hybridization in the aecial stage (33). In this case the common barberry would be another important factor influencing their distribution and prevalence. While the presence of some of these factors and the absence of others may not be sufficient to prevent the appearance of

TABLE 11.—*Prevalence during the 5 years, 1919–1923, inclusive, at various uniform rust nurseries in the United States and Canada of different physiologic forms of Puccinia graminis tritici*

Physiologic forms isolated	Stations from which physiologic forms were isolated in:					Number of localities at which each physiologic form was found during 5-year period
	1919	1920	1921	1922	1923	
1			St. Paul, Minn.			1
3	Ames, Iowa Brookings, S. Dak. Fargo, N. Dak. St. Paul, Minn.	St. Paul, Minn. Brandon, Man. Morden, Man. Rosthern, Sask.				7
5	Brookings, S. Dak.					1
9		Rosthern, Sask.	Crookston, Minn. Edgeley, N. Dak. Brandon, Man. Edmonton, Alta.	Archer, Wyo. Dickinson, N. Dak. Fargo, N. Dak. St. Paul, Minn.		9
11	Archer, Wyo.	Lincoln, Nebr.		Langdon, N. Dak.	Ames, Iowa Archer, Wyo. Crookston, Minn. Fargo, N. Dak. Langdon, N. Dak. St. Paul, Minn.	7
12	St. Paul, Minn.	Indian Head, Sask.				2
13	Lincoln, Nebr.	Lincoln, Nebr.				1
17	Akron, Colo. Mandan, N. Dak.	Mandan, N. Dak. Indian Head, Sask. Rosthern, Sask. Saskatoon, Sask. Winnipeg, Man.	Brookings, S. Dak. St. Paul, Minn. Edmonton, Alta. Winnipeg, Man.	Ames, Iowa Coon Creek, Minn. Duluth, Minn. Fargo, N. Dak. Morris, Minn. Redfield, S. Dak.	Mandan, N. Dak.	15
18			St. Paul, Minn.			1
21			Duluth, Minn. Fargo, N. Dak. Langdon, N. Dak.	Akron, Colo. Brookings, S. Dak. Chatham, Mich. Coon Creek, Minn. Crookston, Minn. Edgeley, N. Dak. Lincoln, Nebr. Madison, Wis. Redfield, S. Dak. Waseca, Minn.	Akron, Colo. Brookings, S. Dak. Coon Creek, Minn. Edgeley, N. Dak. Lincoln, Nebr. Morris, Minn.	14

TABLE 11.—(*Continued*)

Physiologic forms isolated	Stations from which physiologic forms were isolated in:					Number of localities at which each physiologic form was found during 5-year period
	1919	1920	1921	1922	1923	
22	Fargo, N. Dak.					1
24			Saskatoon, Sask.			1
29		Brandon, Man. Edmonton, Alta.	Fargo, N. Dak. St. Paul, Minn. Brandon, Man. Indian Head, Sask. Morden, Man. Rosthern, Sask.		Madison, Wis. Waseca, Minn.	9
30			Ames, Iowa St. Paul, Minn.			2
32		Morden, Man.	Rosthern, Sask. Winnipeg, Man.	St. Paul, Minn.	Chatham, Mich. Coon Creek, Minn. Dickinson, N. Dak. Duluth, Minn. Redfield, S. Dak.	9
34				Archer, Wyo.		1
36			St. Paul, Minn.	Mandan, N. Dak.		2
37			Edgeley, N. Dak. Madison, Wis.			2
38				Mandan, N. Dak.		1
Number of physiologic forms isolated during any one year.	7	8	11	8	5	

the physiologic forms of *P. graminis tritici*, they undoubtedly play a notable rôle in determining the relative prevalence of these forms and the extent of their distribution.

Morphology of Some Important Physiologic Forms

It is of course impossible to distinguish varieties and physiologic forms of *P. graminis* by macroscopic or superficial microscopic examination, although the group forms or varieties can be distinguished from each other by careful measurements of spores.

The study of the comparative morphology of several physiologic forms of *P. graminis tritici* was undertaken to ascertain whether they possessed morphological differences as do the group-forms, or varieties, of *P. graminis* (29, 15, 31). Eight of the more important forms, two of which (3 and 27) consisted of duplicate strains, were chosen for this study. The history and behavior of each form are given in tables 12 and 13.

Form 1 was selected because it is the oldest physiologic form of *P. graminis tritici* now available, having been cultured continuously for more than nine years. It readily attacks half of the 12 differential hosts. The resistant varieties are: Kanred (C. I. 5146) in the *vulgare* group; Arnautka (C. I. 4072), Mindum (C. I. 5296), and Arnautka-"Speltz Marz"-(C. I. 6236) among the durums; and the two emmer varieties, Vernal (C. I. 3686) and Khapli (C. I. 4013).

Form 3 is one of the fairly prevalent forms and was chosen because it differs from form 1 in only two respects: Kanred (C. I. 5146) is entirely immune from form 1 but completely susceptible to form 3; while the contrary is true of Kubanka (C. I. 2094), which is highly susceptible to the first but very resistant to the latter form.

Form 9 is one of the most virulent physiologic forms and rather common in occurrence. It produces heavy infection on all the differential hosts with the exception of Kanred and Khapli.

Form 15 is rare, but it is the most virulent of all the forms so far known, as every one of the differentials, except Khapli, is completely susceptible to it.

Form 17 appears to be the most widely distributed and the most prevalent. It also is quite virulent, being able to infect normally all of the differential hosts except Kanred, Vernal emmer, and Khapli emmer.

Form 27, thus far, has been found only once on the American Continent but has been collected in Asia and in several European countries. Parasitically it is one of the weaker forms, infecting heavily only four of the 12 differential hosts, *viz.*, Little Club (C. I. 4066), Kubanka (C. I. 2094), Acme (C. I. 5284), and Vernal emmer (C. I. 3686). Among the varieties resis-

TABLE 12.—*History of physiologic forms of Puccinia graminis tritici studied morphologically*

Physiologic form	Original host	Place of collection	Date collected	Name of collector	Ultimate host	Culture
1	Wheat	St. Paul, Minn.	Sept. 12, 1915	E. C. Stakman and F. J. Piemeisel	Little Club	Monosporous
3a	do	Stillwater, Okla.	Oct. 18, 1917	E. C. Stakman and Chas. Drechsler	do	Multisporous
3b	do	Lehi, Utah	Aug. 30, 1923	R. U. Cotter	do	Monosporous
9	Barley	De Pere, Wis.	July 27, 1918	R. E. Vaughan	do	do
15	Wheat	Pusa, India	March 12, 1923	R. R. Sen	Vernal	Multisporous
17	Agropyron	Boise, Okla.	Sept. 13, 1923	E. A. Lungren	Little Club	Monosporous
27a	Wheat	Pusa, India	Feb. 26, 1923	R. R. Sen	Vernal	Multisporous
27b	do	Berkeley, Calif.	March 19, 1924	W. W. Mackie	do	do
29	Barley	Huntley, Ill.	June 23, 1922	J. L. Seal	Marquis	do
38	Wheat	Mandan, N. Dak.	Aug. 10, 1922	M. N. Levine	Little Club	do

tant to this form are: Marquis (C. I. 3641), Kota (C. I. 5878), and Einkorn (C. I. 2433), all of which are very susceptible to the five forms enumerated above.

Form 29 is interesting mainly on account of the heterogeneous type of infection it produces on the durum varieties. It occurs rather frequently and is fairly widespread in its distribution.

Form 38 was first isolated in 1922 but has been found several times since then. The reaction of the durum varieties to this form, as to form 29, is indeterminate. The chief difference in the pathogenicity of these two forms appears on two hosts, Marquis and Kanred. Marquis is susceptible to form 29 and resistant to form 38, whereas the opposite is the case with Kanred.

TABLE 13.—*Behavior of physiologic forms of Puccinia graminis tritici studied morphologically, as shown by type of infection produced on differential hosts*

Physiologic forms	Mean reaction of differential varieties of wheat and wheat allies											
	Club	Hard Red Common			Durum					Einkorn	Emmer	
	Little Club C. I. 4066	Marquis C. I. 3641	Kanred C. I. 5146	Kota C. I. 5878	Arnautka C. I. 4072	Mindum C. I. 5296	Arnautka C. I. 6236	Kubanka C. I. 2094	Acme C. I. 5284	Einkorn C. I. 2433	Vernal C. I. 3686	Khapli C. I. 4013
1.....	4	4–	0	3+	1=	1	1=	3+	3++	3	0;	1=
3.....	4	4–	4=	3+	1=	1=	1–	1+	3++	3+	1=	0;
9.....	4	4–	0	3++	4–	4=	4=	4=	3++	3+	4=	1–
15.....	4	4–	4=	3++	4=	4=	4=	3++	3++	3+	4=	1=
17.....	4	4–	0.	3+	4=	4=	4=	3++	3++	3	1=	1=
27.....	4=	2	0	0.	1=	1	1–	4=	3++	1=	4=	1+
29.....	4	4–	0	3	X++	X=	X+	X	X+	3	1–	1–
38.....	4	2=	4–	3++	X+	X=	X+	X++	X++	4–	1=	1+

In the previous studies it was found that 100 spore measurements gave equally as good results as 200 or 400, whereas when less than 100 spores were measured the results were not always representative or conclusive. Inasmuch as the work in the past dealt with varieties, it was not certain that the earlier findings would hold good for the physiologic forms within these varieties. In order to avoid errors which might result from measuring an insufficient number of spores, a large and fully developed uredinium of the monosporous culture of *P. graminis tritici*, form 1 Stak. and Lvne. was selected for the purpose of determining what constitutes an adequate, representative, random sample in the present investigation.

Four hundred spores of the uredinium chosen were measured at one time, and the length and width of each recorded separately. Comparisons

were then made between independent samples of the same and different magnitudes, and also of sub-samples as contrasted with general or composite samples. The probable and standard errors of the differences in the arithmetical means of the values compared were determined by the formulae suggested for the different comparisons by Pearson (22) and Yule (41).

In the case of independent samples, the test of significant and non-significant differences of type was made by comparing the difference of the means (m_1-m_2) with the probable error of this difference, according to the generally accepted formula: $m_1-m_2 \div 0.6745 \sqrt{\sigma_1^2/n_1+\sigma_2^2/n_2}$; where m_1, n_1, σ_1 and m_2, n_2, σ_2 are the respective means, magnitudes and standard deviations of any two independent samples compared.

On the supposition that a quantity is significant when it is β times its standard deviation, or $\beta/0.67449$ times its probable error, Pearson (22) advises the following formula for the significance test of the difference of types in a sub-sample (n, m, σ) and general sample (N, M, Σ), of which the sub-sample is a component part, viz;

$$m-M>\beta\sqrt{\frac{\sigma^2}{n}-\frac{2\sigma^2-\Sigma^2}{N}-\frac{n(M-m)^2}{N(N-n)}}$$

this being true whatever the magnitude of N and n. Pearson (22) states that "using the above formula it may be that a considerable number of cases, for which no proof of significant differentiation has been given, and which have been taken accordingly as having no differentiation, can now be demonstrated to have significant differentiation."

Sub-samples were abstracted, combined, and compared with respective general samples, because it was desired to ascertain how the enlargement of a smaller sample by continuously adding on of more individuals would affect the frequency distribution and the constancy of variates. But, as a sub-sample is made larger and larger, the value of its mean approaches closer and closer to that of the general sample and thus the probable error of the difference becomes less and less and ultimately vanishes. However, by the use of the first formula, it approaches the finite value $0.67449\sqrt{2\Sigma^2/N}$. For this reason the second formula was used in the attempt to determine the possible existence of significant differences between sub-samples and general samples of different magnitudes, though of the same source.

The results obtained are recorded in tables 14 to 17, inclusive. Figures 4 to 9 give a graphic picture of the relative size and shape of the uredinio-spores in the different samples. The curves and the bars are plotted vertically on a logarithmic scale, because it shows the proportional as well as the actual dispersion of the variates in samples of unequal size, and it also enables one to make a direct comparison of rates of change.

TABLE 14.—*Variations and constants for urediniospore lengths of different random samples procured from a single sorus of a monosporous culture of Puccinia graminis tritici form 1*

Lot no.	Random samples studied		Spore classes according to length								Size limits	Constants		
	Type	Magnitude	21μ	24μ	27μ	30μ	33μ	36μ	39μ	42μ		Mean length	Standard deviation	Coefficient of variability
1	Independent	50		1	3	10	14	16	6		23.46—40.25	33.30±0.31	3.21±0.22	9.64±0.65
2		100			2	20	36	33	7	2	25.53—41.17	33.87±0.20	2.98±0.14	8.80±0.42
3		200	1	4	12	29	70	58	21	5	21.16—43.24	33.69±0.18	3.71±0.13	11.01±0.37
4	Composite	50			2	12	9	23	3	1	25.53—40.71	33.96±0.31	3.26±0.22	9.60±0.65
5		100		1	5	22	23	39	9	1	23.46—40.71	33.75±0.23	3.40±0.16	10.07±0.48
6		200		1	7	42	59	72	16	3	23.46—41.17	33.81±0.15	3.20±0.11	9.46±0.32
7		300	1	4	18	59	96	96	22	4	21.16—41.86	33.41±0.13	3.45±0.10	10.32±0.28
8		400	1	5	19	71	129	130	37	8	21.16—43.24	33.75±0.11	3.46±0.08	10.25±0.24

TABLE 15.—*Variations and constants for urediniospore widths of different random samples procured from a single sorus of a monosporous culture of Puccinia graminis tritici form 1*

Lot no.	Random samples studied		Spore classes according to width									Size limits	Constants		
	Type	Magnitude	16μ	17μ	18μ	19μ	20μ	21μ	22μ	23μ	24μ		Mean width	Standard deviation	Coefficient of variability
1	Independent	50			5	3	25	13	3	1		18.17—23.46	20.18±0.10	1.05±0.07	5.20±0.35
2		100	1	2	4	12	45	23	9	4		16.33—23.23	20.23±0.08	1.23±0.06	6.08±0.30
3		200	1	1	12	38	82	39	20	6	1	16.79—24.61	20.32±0.06	1.18±0.04	5.81±0.20
4	Composite	50		1	4	11	19	10	5			17.25—22.54	19.96±0.11	1.15±0.08	5.76±0.39
5		100		1	9	14	44	23	8	1		17.25—23.46	20.07±0.07	1.11±0.05	5.53±0.26
6		200	1	3	13	26	89	46	17	5		16.33—23.46	20.15±0.06	1.17±0.04	5.81±0.20
7		300	2	4	19	45	125	67	31	7		16.33—23.46	20.16±0.05	1.20±0.03	5.95±0.16
8		400	2	4	25	64	171	85	37	11	1	16.33—24.61	20.16±0.04	1.19±0.03	5.90±0.14

TABLE 16.—*Variations and constants for urediniospore shapes of different random samples procured from a single sorus of a monosporous culture of Puccinia graminis tritici form 1*

Lot no.	Random samples studied		Spore classes according to ratio of length to width								Correlation coefficients	Constants		
	Type	Magnitude	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4		Mean ratio	Standard deviation	Coefficient of variability
1	Independent	50		1	9	16	18	3	3		0.139±0.094	1.788=0.021	0.220±0.015	12.30±0.83
2		100		1	13	39	30	13	3	1	0.340±0.060	1.708=0.014	0.212±0.010	12.41±0.59
3		200	2	11	18	71	50	40	5	3	0.358±0.042	1.711±0.012	0.254=0.009	14.85±0.50
4	Composite	50		1	7	17	19	3	3		0.311±0.086	1.700±0.020	0.213=0.014	12.53±0.85
5		100		2	16	33	28	15	6		0.229±0.064	1.712±0.016	0.232=0.011	13.56±0.65
6		200		3	30	72	58	28	9		0.239±0.045	1.705±0.010	0.218=0.007	12.79±0.35
7		300	1	12	41	109	83	42	10	2	0.250±0.032	1.691±0.009	0.233=0.006	13.78±0.38
8		400	2	14	48	141	109	68	14	4	0.460±0.027	1.711±0.008	0.239=0.006	13.97±0.33

TABLE 17.—*Summary of differences between the means of urediniospore dimensions of different random samples procured from a single sorus of a monosporous culture of Puccinia graminis tritici form 1*

Type of samples	Random samples compared	LENGTH		WIDTH		SHAPE	
		Difference in means (in microns)	Difference divided by P. E.	Difference in means (in microns)	Difference divided by P. E.	Difference in means (in microns)	Difference divided by P. E.
INDEPENDENT	50 spores and 50 spores	0.66±0.44	1.50	0.22±0.15	1.47	0.088±0.029	3.03
	do.....100 do	0.57±0.37	1.54	0.05±0.13	0.38	0.080±0.025	3.20
	do.....200 do	0.39±0.36	1.08	0.14±0.12	1.16	0.077±0.024	3.21
	100 spores and 100 spores	0.12±0.30	0.40	0.16±0.11	1.45	0.004±0.021	0.19
	do.....200 do	0.18±0.27	0.67	0.09±0.10	0.90	0.003±0.018	0.67
	200 spores and 200 spores	0.12±0.23	0.52	0.17±0.08	2.13	0.006±0.016	0.38
COMPOSITE	50 spores and 100 spores	0.21±0.33	0.64	0.11±0.11	1.00	0.012±0.022	0.55
	do.....200 do	0.15±0.40	0.38	0.19±0.14	1.36	0.005±0.026	0.19
	do.....300 do	0.55±0.43	1.28	0.20±0.15	1.33	0.009±0.028	0.32
	do.....400 do	0.21±0.44	0.48	0.20±0.15	1.33	0.011±0.029	0.38
	100 spores and 200 spores	0.06±0.22	0.27	0.08±0.08	1.00	0.007±0.015	0.47
	do.....300 do	0.34±0.28	1.21	0.09±0.09	1.00	0.021±0.019	1.11
	do.....400 do	0.00±0.30	0.00	0.09±0.10	0.90	0.001±0.020	0.05
	200 spores and 300 spores	0.40±0.15	2.67	0.01±0.04	0.25	0.014±0.010	1.40
	do.....400 do	0.06±0.17	0.35	0.01±0.06	0.17	0.006±0.012	0.50
	300 spores and 400 spores	0.34±0.10	3.40	0.00±0.03	0.00	0.020±0.007	2.86

The individual spore lots Nos. 1, 2, and 3, and the pair lots 1 and 4, 2 and 5, and 3 and 6 are independent samples. Lot No. 5 is composed of lots 1 and 4; and it in turn is a sub-sample of lot No. 6. Lots 5 and 6 together constitute lot No. 7. All of the sub-samples, of course, enter into the make-up of lot No. 8.

As may be observed from table 17, there seems to be no significant difference between the means of independent samples of 50, 100, and 200 urediniospores procured from the same culture and studied under the same conditions. Likewise, the differences in the size and shape of these spores in composite samples of 50, 100, 200, 300, and 400 measurements may be considered, almost without exception, as quite insignificant statistically. There also was very little difference in the variability of the different lots, in no case much higher than two per cent (See tables 14–16 and figures 4–9).

The probable errors of the means, as might be expected, were consistently and gradually smaller as the sizes of the population were increased. The reduction was in close agreement with the mathematical expectation (19, 41). The contour of the frequency curves in the larger samples, as illustrated in figures 4 and 5 and 7 and 8, approached more nearly that of the "normal" curve. There was no perceptible difference in the mean ratio of the long to the short diameters of the urediniospores in the different

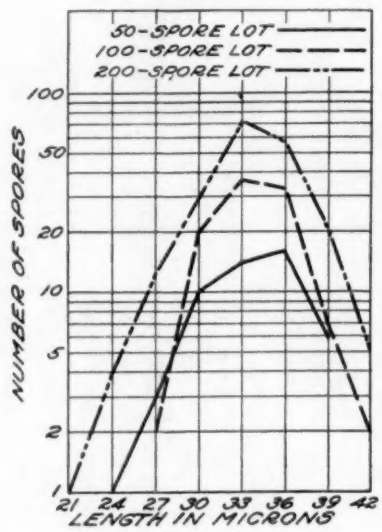


FIG. 4

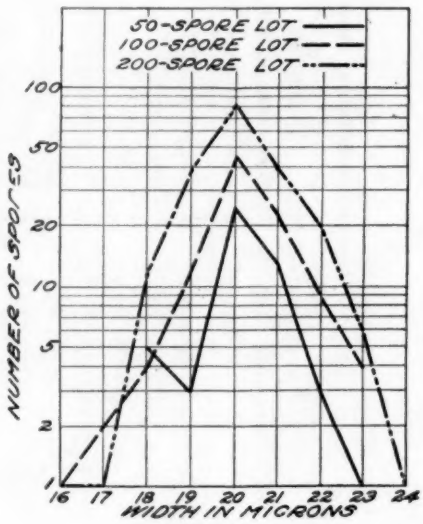


FIG. 5

FIG. 4. Similarity in length of urediniospores of independent random samples of different magnitude obtained from a single sorus of *Puccinia graminis tritici* form 1.

FIG. 5. Similarity in width of urediniospores of independent random samples of different magnitude obtained from a single sorus of *Puccinia graminis tritici* form 1.

lots, with the possible exception of the 50-spore lot No. 1, when compared with the larger independent samples, Nos. 2 and 3.

From the data presented above it would appear that random samples of even 50 spores perhaps might be sufficiently large for a study of the comparative morphology of physiologic forms of *P. graminis tritici*. But because of the relative irregularity in the frequency distribution in the 50-spore lots, it was decided to consider samples of not less than 100 spores as

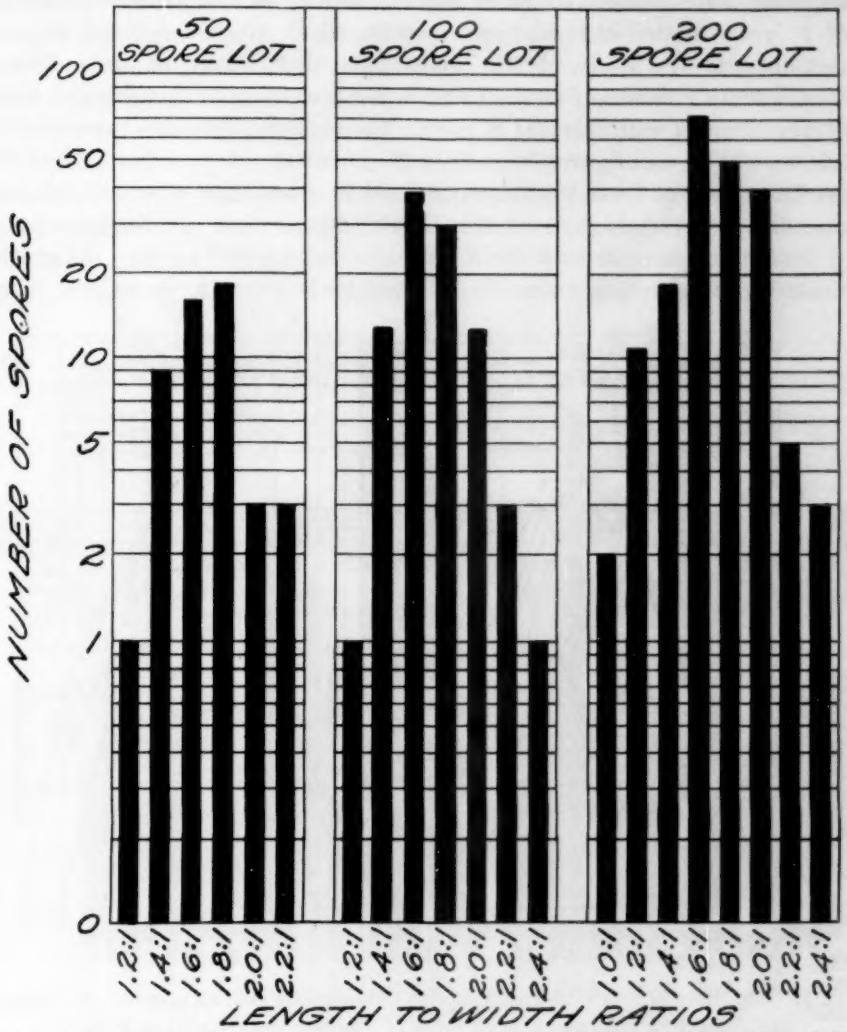


FIG. 6. Similarity in shape of urediniospores of independent random samples of different magnitude obtained from a single sorus of *Puccinia graminis tritici* form 1.

representative and adequate. To ensure that any error in the final analysis would be on the side of caution, the comparisons in the subsequent experiments were made on the basis of random samples consisting in each case of 100 spores, and only those differences are regarded as definitely significant which exceed their probable errors close to five times, *i.e.*, whose chance occurrence would be not more than one in a thousand trials.

Effect of Environmental Conditions.—How great an effect environmental and cultural conditions exert on the morphology of the physiologic forms of *P. graminis tritici* is another question which suggested itself in connection with the study of the comparative morphology of these forms. Monosporous cultures of forms 1 and 3 and a multisporous culture of form 27 were studied with this aim in view. The resulting data are presented in tables 18 to 21 and figures 10 to 18, both inclusive. It was found that the urediniospores of form 1 cultures confined in glass cages when the relative humidity was very high, were considerably longer than the urediniospores of the cultures kept exposed for a considerable length of time on the greenhouse bench. In both cases the infected hosts were the same and there

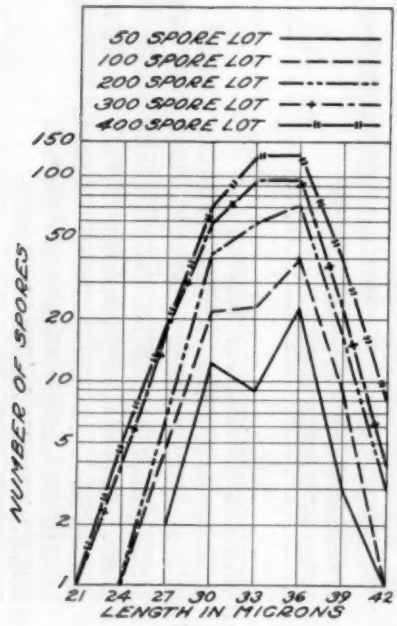


FIG. 7

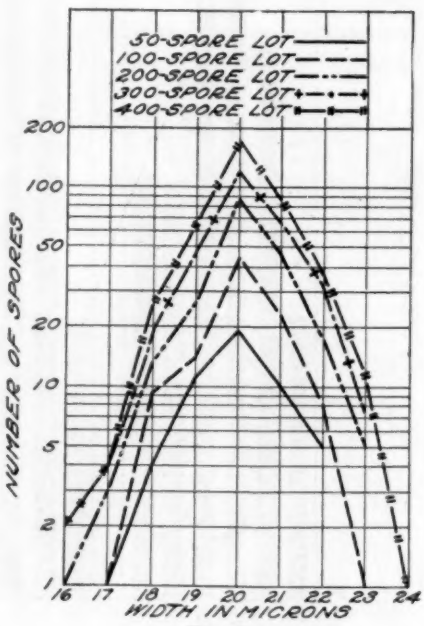


FIG. 8

FIG. 7. Similarity in length of urediniospores of composite random samples of different magnitude obtained from a single sorus of *Puccinia graminis tritici* form 1.

FIG. 8. Similarity in width of urediniospores of composite random samples of different magnitude obtained from a single sorus of *Puccinia graminis tritici* form 1.

was no detectible difference either in type or degree of infection. Only a slight decrease in spore size occurred when a confined culture was exposed for a short period of time (three days). This probably was not statistically significant, as the difference in the mean length was just three times greater than the probable error of the difference and the difference of the mean width was even smaller than its probable error. An etiolated condition of the host caused by an accidental contamination with mold affected the degree of infection somewhat and resulted in a profound decrease in the length and hence also in a change in the shape of the spores.

Urediniospores of form 3, developed on a congenial host (Little Club) and measured 15 days after inoculation in October, showed little difference either in size or shape, when compared with spores of the identical culture and of the same age of development measured in September. The prevailing climatic conditions in both months, as may be seen from table 22, were very much alike, which evidently accounts for the results obtained.

Even a semi-resistant host, such as Federation, appears to reduce the size of the urediniospores cultured on it, decreasing their mean length by

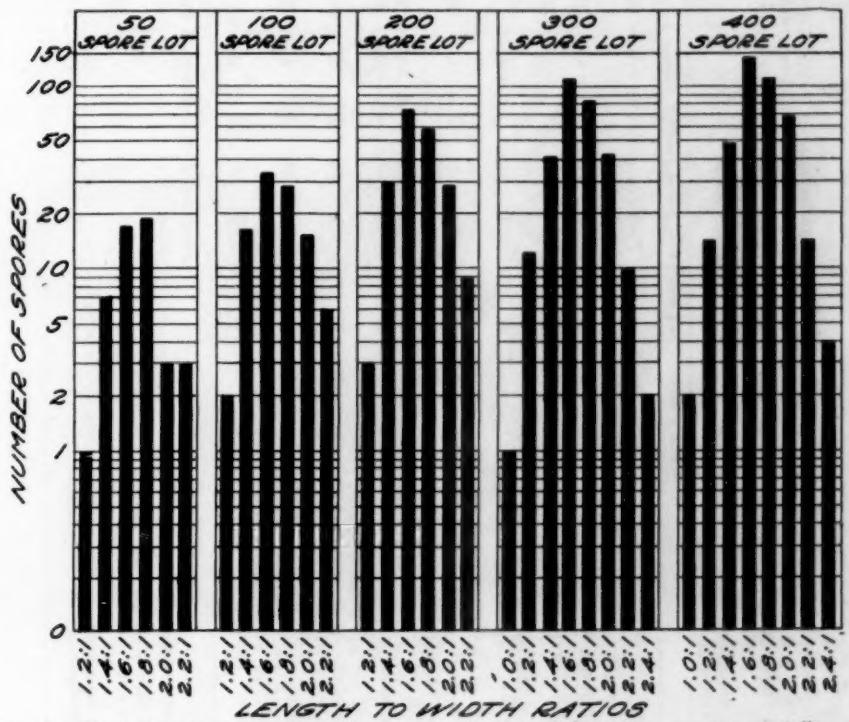


FIG. 9. Similarity in shape of urediniospores of composite random samples of different magnitude obtained from a single sorûs of *Puccinia graminis tritici* form 1.

TABLE 18.—*Variations and constants for length of urediniospores of physiologic forms of Puccinia graminis tritici grown on different host plants, under diverse environmental conditions, and for varying lengths of time*

Cultural conditions	Spore classes according to length								Size limits	Constants		
	21μ	24μ	27μ	30μ	33μ	36μ	39μ	42μ		Mean length	Standard deviation	Coefficient of variability
Puccinia graminis tritici form 1												
Rust inclosed, host vigorous...		1	1	12	33	34	15	4	25.07 – 43.24	34.77 ± 0.22	3.29 ± 0.16	9.46 ± 0.45
Rust inclosed, host etiolated...		12	25	33	16	12	2		23.00 – 37.95	29.91 ± 0.25	3.73 ± 0.18	12.47 ± 0.59
Confined 17 days, exposed 3 days			2	20	36	33	7	2	25.53 – 41.17	33.87 ± 0.20	2.98 ± 0.14	8.80 ± 0.42
Confined 8 days, exposed 24 days	1	4	12	30	34	15	3	1	20.47 – 43.47	31.62 ± 0.24	3.61 ± 0.17	11.42 ± 0.54
Puccinia graminis tritici form 3												
Cultured on Little Club during September		4	8	26	29	25	8		23.46 – 40.02	32.61 ± 0.23	3.38 ± 0.16	10.36 ± 0.49
Cultured on Little Club during October	1	4	4	19	29	26	13	4	20.47 – 43.01	33.63 ± 0.28	4.21 ± 0.20	12.52 ± 0.60
Cultured on Federation during October	1	4	15	24	35	19	2		21.16 – 38.64	31.59 ± 0.24	3.56 ± 0.17	11.27 ± 0.54
Puccinia graminis tritici form 27												
Spores measured 15 days after inoculation	1	18	32	33	13	2	1		19.78 – 38.18	28.47 ± 0.22	3.24 ± 0.15	11.38 ± 0.54
Spores measured 20 days after inoculation	3	13	21	24	25	13	1		21.39 – 39.10	29.94 ± 0.28	4.09 ± 0.20	13.66 ± 0.65

TABLE 19.—*Variations and constants for width of urediniospores of physiologic forms of Puccinia graminis tritici grown on different host plants, under diverse environmental conditions, and for varying lengths of time*

Cultural conditions	Spore classes according to width										Size limits	Constants		
	15μ	16μ	17μ	18μ	19μ	20μ	21μ	22μ	23μ	24μ		Mean width	Standard deviation	Coefficient of variability
Puccinia graminis tritici form 1														
Rust inclosed, host vigorous				6	19	46	18	6	4	1	18.17 – 24.61	20.15 ± 0.08	1.16 ± 0.06	5.76 ± 0.27
Rust inclosed, host etiolated		1	8	9	18	35	15	7	5	2	16.79 – 24.38	19.88 ± 0.11	1.62 ± 0.08	8.15 ± 0.39
Confined 17 days, exposed 3 days		1	2	4	12	45	23	9	4		16.33 – 23.23	20.23 ± 0.08	1.23 ± 0.06	6.08 ± 0.30
Confined 8 days, exposed 24 days			1	3	18	31	27	15	5		17.25 – 23.46	20.45 ± 0.08	1.23 ± 0.06	6.01 ± 0.29
Puccinia graminis tritici form 3														
Cultured on Little Club during September		1	1	8	17	45	17	9	2		16.79 – 23.69	20.01 ± 0.08	1.20 ± 0.06	6.00 ± 0.29
Cultured on Little Club during October			3	17	24	35	14	6	1		17.25 – 23.23	19.62 ± 0.08	1.23 ± 0.06	6.27 ± 0.30
Cultured on Federation during October			7	15	32	33	9	3	1		17.02 – 23.00	19.35 ± 0.08	1.20 ± 0.06	6.20 ± 0.30
Puccinia graminis tritici form 27														
Spores measured 15 days after inoculation	3	3	6	18	30	21	12	7			15.18 – 22.77	19.15 ± 0.11	1.57 ± 0.07	8.20 ± 0.39
Spores measured 20 days after inoculation			4	15	26	38	14	2	1		17.02 – 23.00	19.53 ± 0.08	1.14 ± 0.05	5.84 ± 0.28

TABLE 20.—*Variations and constants for shape of urediniospores of physiologic forms of Puccinia graminis tritici grown on different host plants, under diverse environmental conditions, and for varying lengths of time*

Cultural conditions	Spore classes according to ratio of length to width								Correlation coefficient	Constants		
	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4		Mean ratio	Standard deviation	Coefficient of variability
***Puccinia graminis tritici* form 1**												
Rust inclosed, host vigorous	1	2	7	32	26	26	4	2	− 0.557 ± 0.047	1.768 ± 0.017	0.246 ± 0.012	13.91 ± 0.66
Rust inclosed, host etiolated	1	20	23	31	19	4	1	1	− 0.126 ± 0.066	1.536 ± 0.017	0.254 ± 0.012	16.54 ± 0.79
Confined 17 days, exposed 3 days		1	13	39	30	13	3	1	− 0.340 ± 0.060	1.708 ± 0.014	0.212 ± 0.010	12.41 ± 0.59
Confined 8 days, exposed 24 days	2	13	15	44	18	7	1		− 0.273 ± 0.062	1.576 ± 0.016	0.235 ± 0.011	14.91 ± 0.71
***Puccinia graminis tritici* form 3**												
Cultured on Little Club during September	1	7	12	42	20	14	4		− 0.329 ± 0.060	1.662 ± 0.017	0.246 ± 0.012	14.80 ± 0.71
Cultured on Little Club during October	2	6	8	29	31	18	4	2	− 0.336 ± 0.060	1.722 ± 0.018	0.271 ± 0.013	15.74 ± 0.75
Cultured on Federation during October	2	11	11	31	26	16	3		− 0.483 ± 0.052	1.656 ± 0.018	0.270 ± 0.013	16.30 ± 0.78
***Puccinia graminis tritici* form 27**												
Spores measured 15 days after inoculation	3	20	26	34	11	3	2	1	− 0.308 ± 0.061	1.504 ± 0.017	0.258 ± 0.012	17.15 ± 0.82
Spores measured 20 days after inoculation	3	19	17	32	17	11	1		− 0.295 ± 0.062	1.556 ± 0.018	0.272 ± 0.013	17.49 ± 0.83

TABLE 21.—*Summary of differences between the means of the dimensions of urediniospores of physiologic forms of Puccinia graminis tritici grown on different host plants, under diverse environmental conditions, and for varying lengths of time*

Cultural conditions compared	LENGTH		WIDTH		SHAPE	
	Difference in means (in microns)	Difference divided by P. E.	Difference in means (in microns)	Difference divided by P. E.	Difference in means (in microns)	Difference divided by P. E.
Puccinia graminis tritici form 1						
Rust inclosed, host vigorous and rust inclosed, host etiolated	4.86 ± 0.33	14.73	0.27 ± 0.14	1.93	0.232 ± 0.024	9.67
Confined 17 days, exposed 0 days and confined 17 days, exposed 3 days	0.90 ± 0.30	3.00	0.08 ± 0.11	0.73	0.060 ± 0.022	2.73
Confined 17 days, exposed 0 days and confined 8 days, exposed 24 days	3.15 ± 0.33	9.55	0.30 ± 0.11	2.73	0.192 ± 0.023	8.35
Confined 17 days, exposed 3 days and confined 8 days, exposed 24 days	2.25 ± 0.31	7.26	0.22 ± 0.11	2.00	0.132 ± 0.021	6.29
Puccinia graminis tritici form 3						
Cultured on Little Club in September and cultured on Little Club in October	1.02 ± 0.36	2.83	0.39 ± 0.11	3.55	0.060 ± 0.025	2.40
Cultured on Little Club in September and cultured on Federation in October	1.02 ± 0.33	3.09	0.66 ± 0.11	6.00	0.006 ± 0.025	0.24
Cultured on Little Club in October and cultured on Federation in October	2.04 ± 0.39	5.23	0.27 ± 0.11	2.45	0.066 ± 0.025	2.64
Puccinia graminis tritici form 27						
Measured 15 days after inoculation and measured 20 days after inoculation	1.47 ± 0.36	4.08	0.38 ± 0.14	2.71	0.052 ± 0.025	2.08

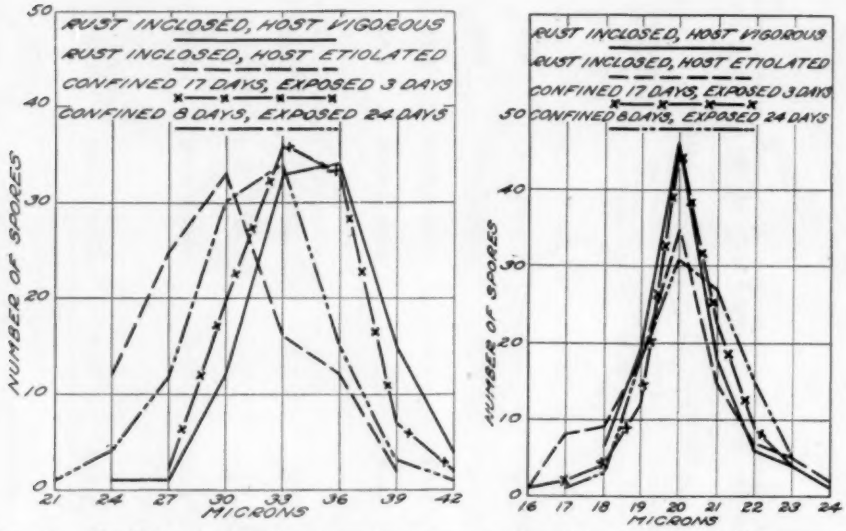

RUST INCLOSED, HOST VIGOROUS
RUST INCLOSED, HOST ETIOLATED
CONFINED 17 DAYS, EXPOSED 3 DAYS
CONFINED 8 DAYS, EXPOSED 24 DAYS
NUMBER OF SPORES
MICRONS
RUST INCLOSED, HOST VIGOROUS
RUST INCLOSED, HOST ETIOLATED
CONFINED 17 DAYS, EXPOSED 3 DAYS
CONFINED 8 DAYS, EXPOSED 24 DAYS
NUMBER OF SPORES
MICRONS

FIG. 10. Variation in length of urediniospores of *Puccinia graminis tritici* form 1, cultured under favorable and adverse environmental conditions.

FIG. 11. Variation in width of urediniospores of *Puccinia graminis tritici* form 1, cultured under favorable and adverse environmental conditions.

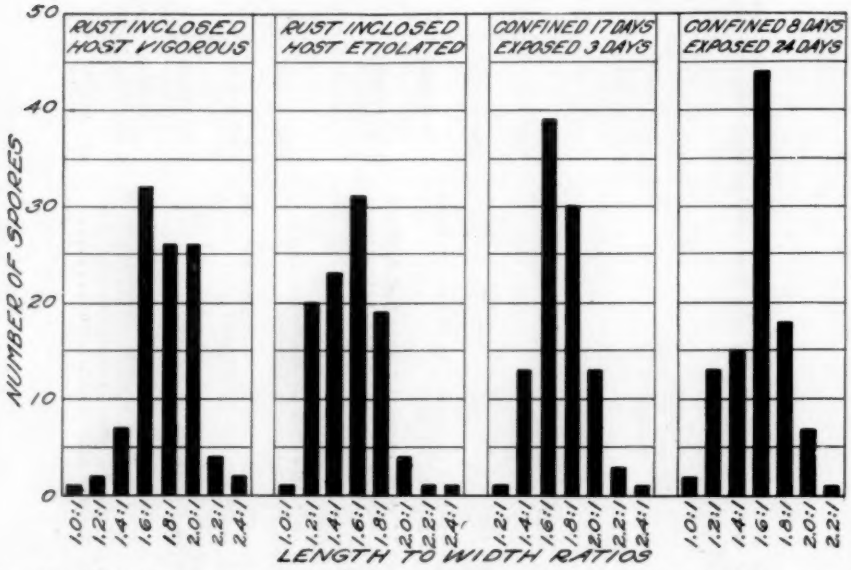


FIG. 12. Variation in shape of urediniospores of *Puccinia graminis tritici* form 1, cultured under favorable and adverse environmental conditions.

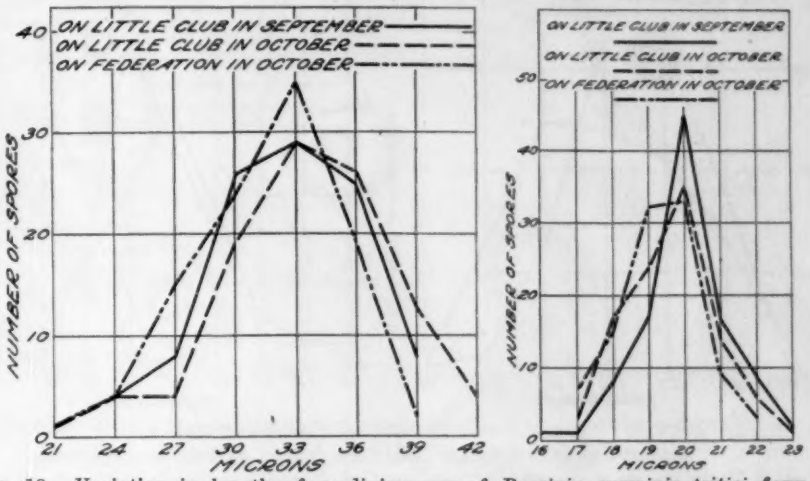

ON LITTLE CLUB IN SEPTEMBER
ON LITTLE CLUB IN OCTOBER
ON FEDERATION IN OCTOBER
NUMBER OF SPORES
MICRONS
0 10 20 30 40
21 24 27 30 33 36 39 42
16 17 18 19 20 21 22 23

FIG. 13. Variation in length of urediniospores of *Puccinia graminis tritici* form 3, cultured at different times and on different hosts.

FIG. 14. Variation in width of urediniospores of *Puccinia graminis tritici* form 3, cultured at different times and on different hosts.

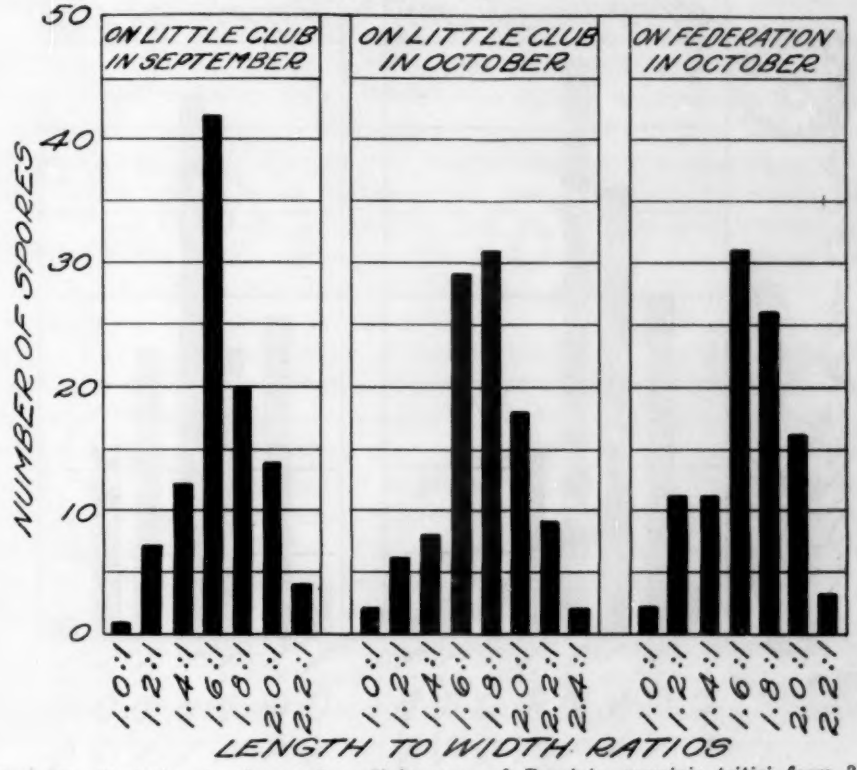

ON LITTLE CLUB IN SEPTEMBER
ON LITTLE CLUB IN OCTOBER
ON FEDERATION IN OCTOBER
NUMBER OF SPORES
0 10 20 30 40 50
1:0:1 1:2:1 1:4:1 1:6:1 1:8:1 2:0:1 2:2:1
1:0:1 1:2:1 1:4:1 1:6:1 1:8:1 2:0:1 2:2:1 2:4:1
1:0:1 1:2:1 1:4:1 1:6:1 1:8:1 2:0:1 2:2:1
LENGTH TO WIDTH RATIOS

FIG. 15. Variation in shape of urediniospores of *Puccinia graminis tritici* form 3, cultured at different times and on different hosts.

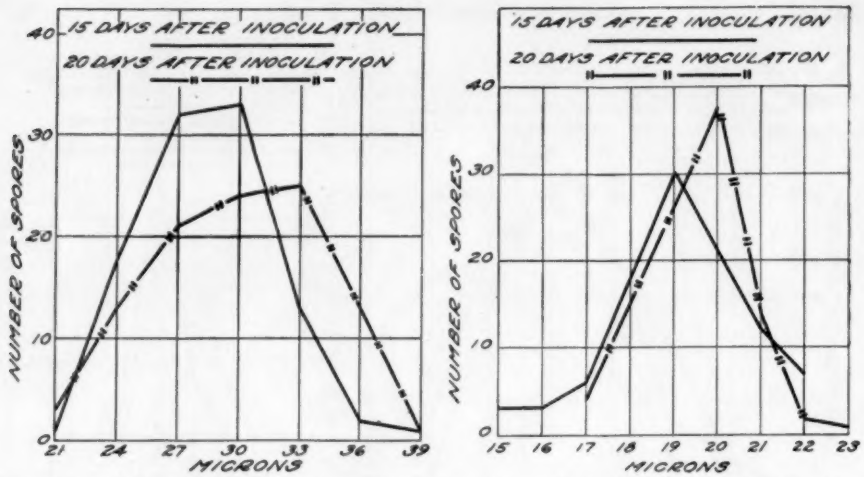


FIG. 16. Variation in length of urediniospores of *Puccinia graminis tritici* form 27, measured after different periods from date of inoculation.

FIG. 17. Variation in width of urediniospores of *Puccinia graminis tritici* form 27, measured after different periods from date of inoculation.

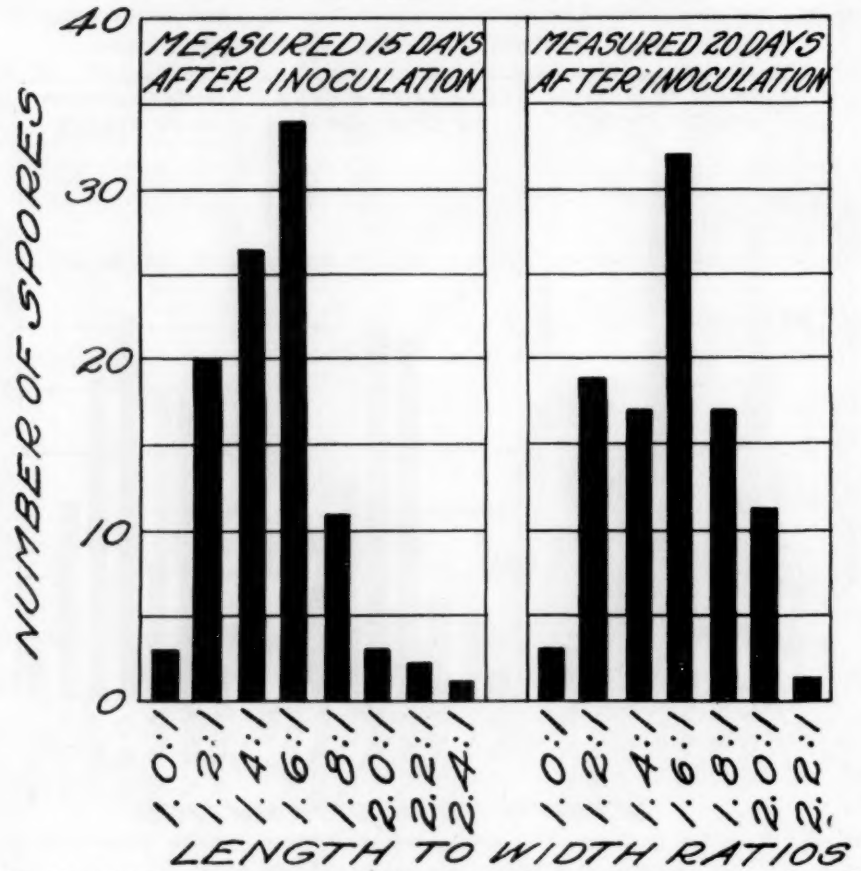


FIG. 18. Variation in shape of urediniospores of *Puccinia graminis tritici* form 27, measured after different periods from date of inoculation.

TABLE 22.—*Summary of prevailing temperature and light conditions at St. Paul, Minn., during September and October, 1924*

Weather conditions	September	October
Temperature (Degrees Fahrenheit)		
Maximum	65.2	65.7
Minimum	48.2	46.0
Mean	56.7	55.8
Condition of Sky		
No. days clear	10	14
No. days partly cloudy	10	10
No. days cloudy	10	7
Sunshine		
Per cent of possible	53	66

from 1 to 2 microns and their mean width by from 1/4 to 2/3 microns. In all cases these differences seem to be quite significant.

Maturity of the urediniospores also has considerable to do with their relative size. The data regarding the effect of ecological factors on the size and shape of urediniospores of physiologic forms of *P. graminis tritici* are presented in detail in tables 18 to 22 and in figures 10 to 18, inclusive.

Influence of Geographic Habitat.—Are physiologic forms of *P. graminis tritici,* identical in their parasitic behavior on the differential varieties of wheat, but of different geographical origin, similar or dissimilar in their morphologic structure? To gain knowledge concerning this point, a strain of form 3, collected in Utah in 1923, was compared with the prototype culture of this form, collected in Oklahoma in 1917. Likewise two strains of form 27, one from India, collected in 1923, and another from California, collected in 1924, were compared. The facts regarding these cultures are given in tables 23 to 26 and figures 19 to 24, inclusive.

There was a difference of 1.29 ± 0.39 microns in the mean length and 0.68 ± 0.11 in the mean width of the two strains of form 3 in favor of the Utah culture. Both of these differences very probably are significant. However, the two strains were studied at different times, and other factors may have played a part, which might account for the differences. On the other hand, the differences may be genetic in nature and due perhaps to the fact that on other differential hosts the two strains might be shown to be distinct physiologic forms. There also is the possibility that even though the two strains possessed the same parasitic capabilities their morphologic evolution in Utah and California might have been different.

In the case of form 27 the two strains were grown on identical hosts (Vernal emmer), inoculated on the same date and measured on the same day. And yet, although there was practically no difference in the mean

TABLE 23.—*Variations and constants for length of urediniospores of physiologic forms of Puccinia graminis tritici, originated under separate geographic conditions*

Place of origin	Spore classes according to length								Size limits	Constants		
	21μ	24μ	27μ	30μ	33μ	36μ	39μ	42μ		Mean	Standard deviation	Coefficient of variability
P. graminis tritici form 3												
Stillwater, Okla.		3	12	25	31	22	7		23.68 — 40.00	32.34 ± 0.24	3.61 ± 0.17	11.16 ± 0.53
Lehi, Utah	1	4	4	19	29	26	13	4	20.47 — 43.01	33.63 ± 0.28	4.21 ± 0.20	12.52 ± 0.60
P. graminis tritici form 27												
Pusa, India	2	10	24	27	25	11	1		20.47 = 37.72	30.00 ± 0.26	3.79 ± 0.18	12.63 ± 0.60
Berkeley, Calif.	3	13	21	24	25	13	1		21.39 — 39.10	29.94 ± 0.28	4.09 ± 0.20	13.66 ± 0.65

TABLE 24.—*Variations and constants for width of urediniospores of physiologic forms of Puccinia graminis tritici, originated under separate geographic conditions*

Place of origin	Spore classes according to width									Size limits	Constants		
	16μ	17μ	18μ	19μ	20μ	21μ	22μ	23μ	24μ		Mean	Standard deviation	Coefficient of variability
P. graminis tritici form 3													
Stillwater, Okla.	1	6	21	48	18	6				16.96 — 21.76	18.94 ± 0.07	0.98 ± 0.05	5.17 ± 0.25
Lehi, Utah		3	17	24	35	14	6	1		17.25 — 23.23	19.62 ± 0.08	1.23 ± 0.06	6.27 ± 0.30
P. graminis tritici form 27													
Pusa, India		3	10	27	18	18	11	11	2	17.25 — 24.84	20.25 ± 0.11	1.68 ± 0.08	8.30 ± 0.40
Berkeley, Calif.		4	15	26	38	14	2	1		17.02 — 23.00	19.53 ± 0.08	1.14 ± 0.05	5.84 ± 0.28

TABLE 25.—*Variations and constants for shape of urediniospores of physiologic forms of Puccinia graminis tritici, originated under separate geographic conditions*

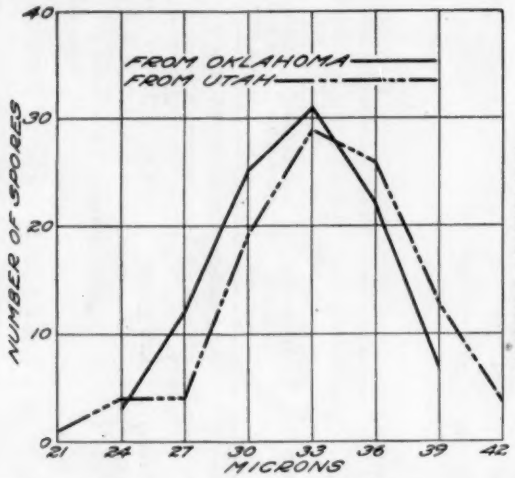
Place of origin	Spore classes according to ratio of length to width								Correlation coefficient	Constants		
	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4		Mean ratio	Standard deviation	Coefficient of variability
Puccinia graminis tritici form 3												
Stillwater, Okla.		6	9	29	30	18	8		−0.435 ± 0.055	1.738 ± 0.017	0.253 ± 0.012	14.56 ± 0.69
Lehi, Utah	2	6	8	29	31	18	4	2	−0.336 ± 0.060	1.722 ± 0.018	0.271 ± 0.013	15.74 ± 0.75
Puccinia graminis tritici form 27												
Pusa, India	1	18	28	34	15	3	1		+0.212 ± 0.064	1.514 ± 0.015	0.225 ± 0.011	15.91 ± 0.76
Berkeley, Calif.	3	19	17	32	17	11	1		−0.295 ± 0.062	1.556 ± 0.018	0.272 ± 0.013	17.49 ± 0.83

TABLE 26.—*Summary of differences between the means of the dimensions of urediniospores of physiologic forms of Puccinia graminis tritici, originated under separate geographic conditions*

Physiologic forms of diverse origin compared	LENGTH		WIDTH		SHAPE	
	Difference in means (in microns)	Difference divided by P. E.	Difference in means (in microns)	Difference divided by P. E.	Difference in means (in microns)	Difference divided by P. E.
Puccinia graminis tritici form 3						
Form 3, Oklahoma strain, and form 3, Utah strain	1.29 ± 0.39	3.31	0.68 ± 0.11	6.18	0.016 ± 0.025	0.64
Puccinia graminis tritici form 27						
Form 27, India strain, and form 27, California strain	0.06 ± 0.38	0.16	0.72 ± 0.14	5.14	0.042 ± 0.023	1.83

length of spores of the two strains ($0.06 \pm 0.38\,\mu$), the mean width of the spores of the India strain was $0.72 \pm 0.14\,\mu$ greater than that of the California strain, a difference which exceeds its probable error 5.14 times and is not likely to be due to random sampling. Here again arises the question of the effect of origin on the morphology of presumably identical strains of a given physiologic form. It would not be safe to draw any definite conclusions from this experiment, for even here some environmental factor, possibly light, may have affected the result. The India strain was grown on the bench, near the outer glass wall of the greenhouse, while the California strain was on the opposite side, facing a brick wall. The situation needs to be reversed and further studies made in order to gain conclusive knowledge.

It is interesting to note in this connection that there was no appreciable difference in the shape of the two strains of form 3; likewise there appeared to be no significant biometrical difference in the shape of spores of the two strains of form 27.



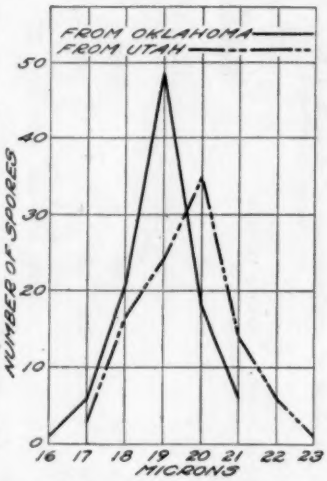


FIG. 19. Variation in length of urediniospores of *Puccinia graminis tritici* form 3, originated under diverse geographic conditions.

FIG. 20. Variation in width of urediniospores of *Puccinia graminis tritici* form 3, originated under diverse geographic conditions.

Comparative Anatomy Under Similar Conditions.—Four of the eight forms selected for the comparative morphological study (forms 1, 3, 9, and 17) were of monosporous origin and were cultured in closed, spore-proof, glass cages. The other four (forms 15, 27, 29, and 38) were multisporous stock cultures, grown in open compartments on the greenhouse benches. Otherwise the forms were cultured under virtually identical conditions and on congenial hosts. Form 15 was chosen because of its extreme

virulence, being able to infect heavily all the differential hosts of *Puccinia graminis tritici* except Khapli. Form 27, on the other hand, was chosen because it is the weakest physiologic form of the wheat stem rust now available; it produces normal infection only on Little Club, Kubanka, Acme, and Vernal emmer. Form 1 is the oldest culture on hand and attacks the hard red spring wheats very heavily, but half of the differential hosts are highly resistant to it. Forms 3, 9, 17, and 29 occur very frequently, are widely distributed, and rather virulent. Form 38, like form 29, produces a heterogeneous type of infection on the durum varieties. Marquis is very resistant to form 38 and Kanred is completely susceptible to it; the reverse is true for form 29.

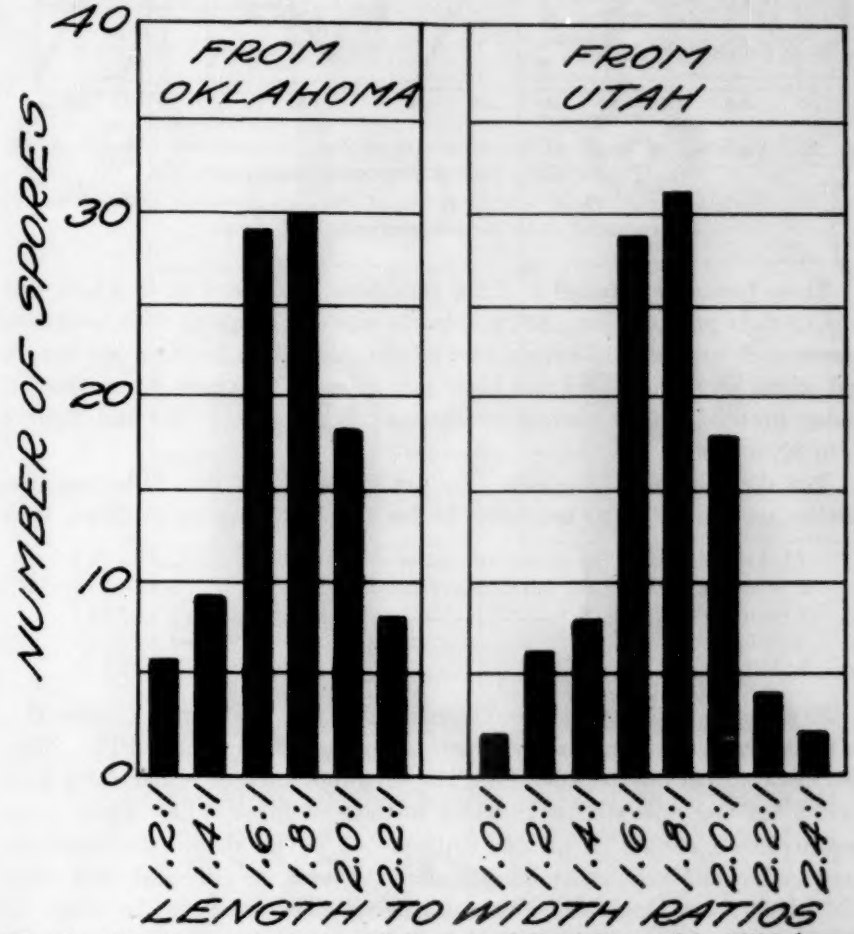
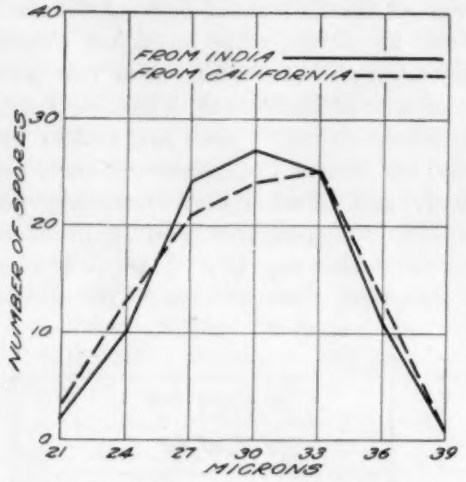


FIG. 21. Variation in shape of urediniospores of *Puccinia graminis tritici* form 3, originated under diverse geographic conditions.



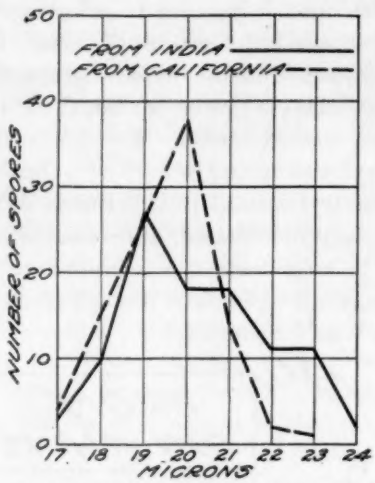


FIG. 22. Variation in length of urediniospores of *Puccinia graminis tritici* form 27, originated under diverse geographic conditions.

FIG. 23. Variation in width of urediniospores of *Puccinia graminis tritici* form 27, originated under diverse geographic conditions.

These forms were found to differ significantly, in part or in whole, not only in their pathogenicity, but also in the size and shape of their urediniospores, and, to a certain extent, also in the correlation between the length and width of these spores and their morphogenic processes when studied under uniform environmental conditions (See tables 27–30 and figures 25 to 30, inclusive.

For the sake of convenience, the urediniospores in the following discussion are considered as belonging to five classes, according to shape, viz.:

1. Spherical, embracing spores with ratios approximating		1.0 : 1
2. Spheroidal, comprising individuals within ratio classes		1.0 : 1 to 1.2 : 1
3. Subglobose,	do	1.4 : 1 to 1.6 : 1
4. Ellipsoid,	do	1.8 : 1 to 2.0 : 1
5. Elliptical,	do	2.2 : 1 to 2.4 : 1

P. graminis tritici form 1.—The urediniospores of form 1 (Table 31), on the average, are significantly longer than those of forms 9 and 17. They also are considerably broader than the urediniospores of either form 3 or form 9 but are quite similar in width to those of form 17 : 1. Their mean measurements are $34.77 \pm 0.22 \times 20.15 \pm 0.08\ \mu$. In shape, the urediniospores of form 1 are predominantly elongate-ovate, or elliptical, and ellipsoid, their mean length-to-width ratio being 1.768 ± 0.017. In shape as well as in size the urediniospores of form 1 are the least variable among the monosporous forms. There appears to be a definite negative correlation of

0.557 ± 0.047 between the long and short diameters of these spores (the highest correlation among all the forms studied), but the percentage of variability does not exceed 17 per cent (16.95 per cent to be exact). This, however, is the highest percentage of variability encountered in this study. The percentage of variability controlled by the correlation, r, was determined by the formula $100 \times (1 - \sqrt{1 - r^2})$.

P. graminis tritici form 3.—The mean dimensions of the urediniospores of form 3 (Table 32) are $33.63 \pm 0.28 \times 19.62 \pm 0.08\ \mu$; on the average, $1.14 \pm 0.36\ \mu$ shorter and $0.53 \pm 0.11\ \mu$ narrower than those of form 1.

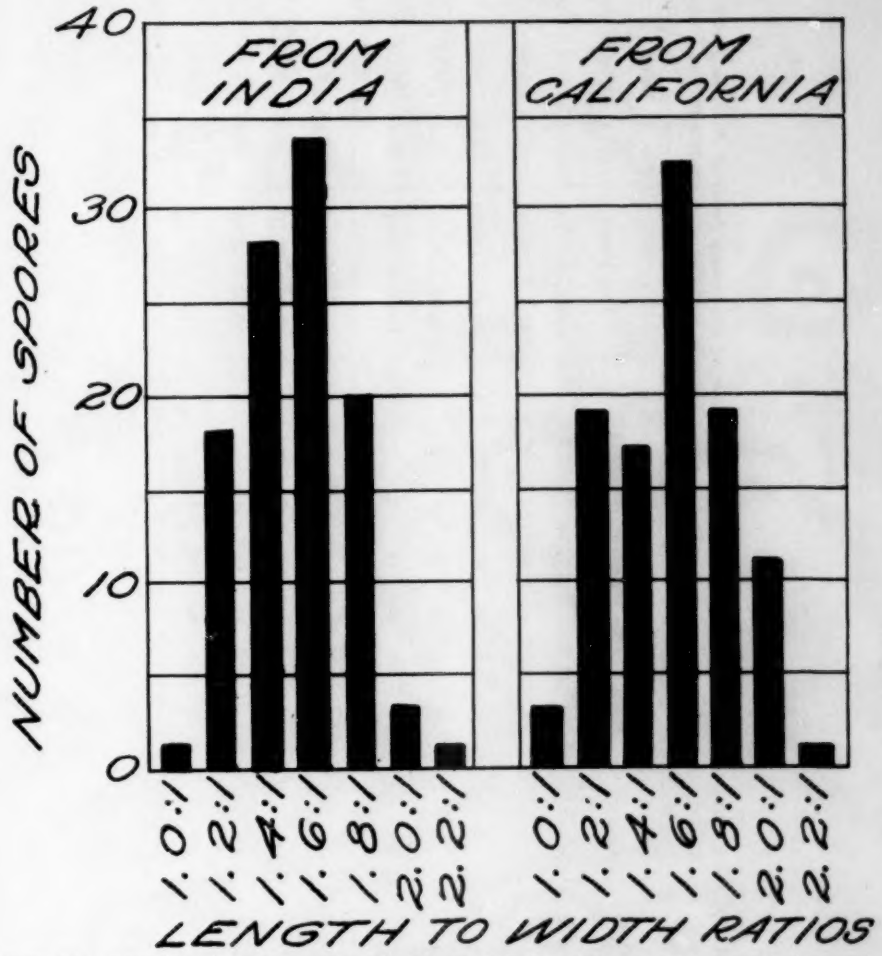


FIG. 24. Variation in shape of urediniospores of *Puccinia graminis tritici* form 27, originated under diverse geographic conditions.

TABLE 27.—*Variations and constants for length of urediniospores of physiologic forms of Puccinia graminis tritici, grown on congenial host plants and under uniform environmental conditions*

Type of culture	Form	Spore classes according to length								Size limits	Constants		
		21μ	24μ	27μ	30μ	33μ	36μ	39μ	42μ		Mean length	Standard deviation	Coefficient of variability
MONOSPOROUS	1		1	1	12	33	34	15	4	25.07 – 43.24	34.77 ± 0.22	3.29 ± 0.16	9.46 ± 0.45
	3	1	4	4	19	29	26	13	4	20.47 – 43.01	33.63 ± 0.28	4.21 ± 0.20	12.52 ± 0.60
	9	1	3	14	35	28	17	2		21.62 – 40.25	31.35 ± 0.23	3.40 ± 0.16	10.85 ± 0.52
	17	1	7	26	40	24	2			22.08 – 36.57	29.55 ± 0.19	2.89 ± 0.14	9.78 ± 0.47
MULTISPOROUS	15	1	2	11	22	36	26	2		22.08 – 39.10	32.28 ± 0.23	3.40 ± 0.16	10.53 ± 0.50
	27	3	13	21	24	25	13	1		21.39 – 39.10	29.94 ± 0.28	4.09 ± 0.20	13.66 ± 0.65
	29	2	11	31	41	14	1			20.47 – 35.65	28.71 ± 0.19	2.89 ± 0.14	10.07 ± 0.48
	38		2	17	30	34	14	3		24.15 – 39.79	31.50 ± 0.22	3.24 ± 0.15	10.29 ± 0.49

TABLE 28.—*Variations and constants for width of urediniospores of physiologic forms of Puccinia graminis tritici grown on congenial host plants under uniform environmental conditions*

Type of culture	Form	Spore classes according to width										Size limits	Constants		
		16μ	17μ	18μ	19μ	20μ	21μ	22μ	23μ	24μ	25μ		Mean width	Standard deviation	Coefficient of variability
MONOSPOROUS	1			6	19	46	18	6	4	1		18.17 — 24.61	20.15 ± 0.08	1.16 ± 0.06	5.76 ± 0.27
	3		3	17	24	35	14	6	1			17.25 — 23.23	19.62 ± 0.08	1.23 ± 0.06	6.27 ± 0.30
	9	2	7	23	30	23	9	5	1			16.56 — 23.46	19.17 ± 0.09	1.36 ± 0.06	7.09 ± 0.34
	17	1	1	4	16	36	30	10	1	1		16.10 — 24.38	20.26 ± 0.08	1.20 ± 0.06	5.92 ± 0.28
MULTISPOROUS	15				2	13	24	32	20	7	2	19.32 — 25.99	21.84 ± 0.08	1.25 ± 0.06	5.72 ± 0.27
	27		4	15	26	38	14	2	1			17.02 — 23.00	19.53 ± 0.08	1.14 ± 0.05	5.84 ± 0.28
	29		5	11	38	35	8	2	1			17.71 — 23.69	19.40 ± 0.07	1.08 ± 0.05	5.57 ± 0.27
	38		1	7	20	32	30	9	1			17.94 — 23.23	20.14 ± 0.08	1.14 ± 0.05	5.66 ± 0.27

TABLE 29.—*Variations and constants for shape of urediniospores of physiologic forms of Puccinia graminis tritici, grown on congenial host plants and under uniform environmental conditions*

Type of culture	Form	Spore classes according to ratio of length to width								Correlation coefficient	Constants		
		1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4		Mean ratio	Standard deviation	Coefficient of variability
MONOSPOROUS	1	1	2	7	32	26	26	4	2	− 0.557 ± 0.047	1.768 ± 0.017	0.246 ± 0.012	13.91 ± 0.66
	3	2	6	8	29	31	18	4	2	− 0.336 ± 0.060	1.722 ± 0.018	0.271 ± 0.013	15.74 ± 0.75
	9	3	8	11	37	24	11	6		− 0.522 ± 0.049	1.656 ± 0.017	0.252 ± 0.012	15.21 ± 0.73
	17	2	24	27	33	13	1			− 0.397 ± 0.057	1.468 ± 0.014	0.214 ± 0.010	15.27 ± 0.73
MULTISPOROUS	15	4	12	25	42	14	3			− 0.357 ± 0.059	1.518 ± 0.015	0.217 ± 0.010	14.29 ± 0.68
	27	3	19	17	32	17	11	1		− 0.295 ± 0.062	1.556 ± 0.018	0.272 ± 0.013	17.49 ± 0.83
	29	2	15	29	41	11	2			− 0.259 ± 0.063	1.500 ± 0.014	0.201 ± 0.010	13.40 ± 0.64
	38		10	24	36	22	6	2		− 0.003 ± 0.067	1.592 ± 0.015	0.225 ± 0.011	14.13 ± 0.67

TABLE 30.—*Summary of differences between the means of the dimensions of urediniospores of physiologic forms of Puccinia graminis tritici, grown on congenial host plants and under uniform environmental conditions*

Type of culture	Physiologic forms compared	LENGTH		WIDTH		SHAPE	
		Difference in means (in microns)	Difference divided by P. E.	Difference in means (in microns)	Difference divided by P. E.	Difference in means (in microns)	Difference divided by P. E.
MONOSPOROUS	1 and 3	1.14 ± 0.36	3.17	0.53 ± 0.11	4.82	0.046 ± 0.025	1.84
	1 and 9	3.42 ± 0.32	10.69	0.98 ± 0.12	8.17	0.112 ± 0.024	4.67
	1 and 17	5.22 ± 0.29	17.99	0.11 ± 0.11	1.00	0.300 ± 0.022	13.64
	3 and 9	2.28 ± 0.36	6.33	0.45 ± 0.12	3.75	0.066 ± 0.025	2.64
	3 and 17	4.08 ± 0.34	12.00	0.64 ± 0.11	5.82	0.254 ± 0.023	11.04
	9 and 17	1.80 ± 0.30	6.00	1.09 ± 0.12	9.08	0.188 ± 0.022	8.55
MULTISPOROUS	15 and 27	2.34 ± 0.36	6.50	2.31 ± 0.11	21.00	0.038 ± 0.023	1.65
	15 and 29	3.57 ± 0.30	11.90	2.44 ± 0.11	22.18	0.018 ± 0.021	0.86
	15 and 38	0.78 ± 0.32	2.44	1.70 ± 0.11	15.45	0.074 ± 0.021	3.52
	27 and 29	1.23 ± 0.34	3.62	0.13 ± 0.11	1.18	0.056 ± 0.023	2.43
	27 and 38	1.56 ± 0.36	4.33	0.61 ± 0.11	5.55	0.036 ± 0.023	1.57
	29 and 38	2.79 ± 0.29	9.62	0.74 ± 0.11	6.73	0.092 ± 0.021	4.38

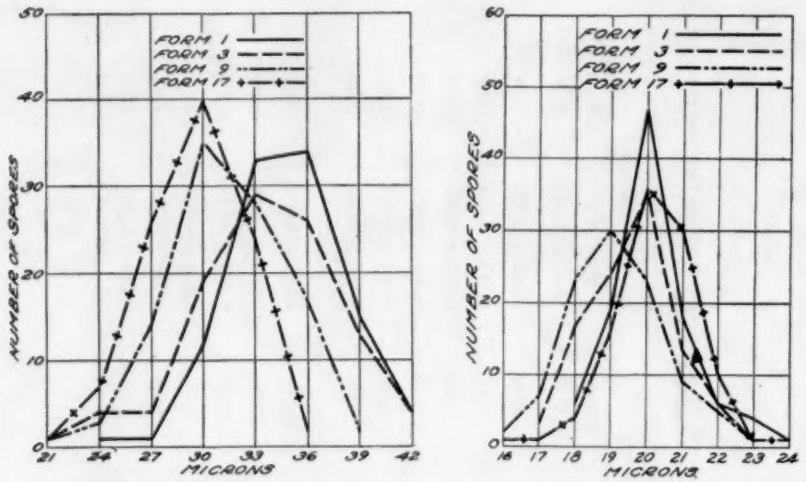


FIG. 25. Differences in urediniospore length of monosporous cultures of four physiologic forms of *Puccinia graminis tritici*, grown on congenial host plants and under uniform environmental conditions.

FIG. 26. Differences in urediniospore width of monosporous cultures of four physiologic forms of *Puccinia graminis tritici*, grown on congenial host plants and under uniform environmental conditions.

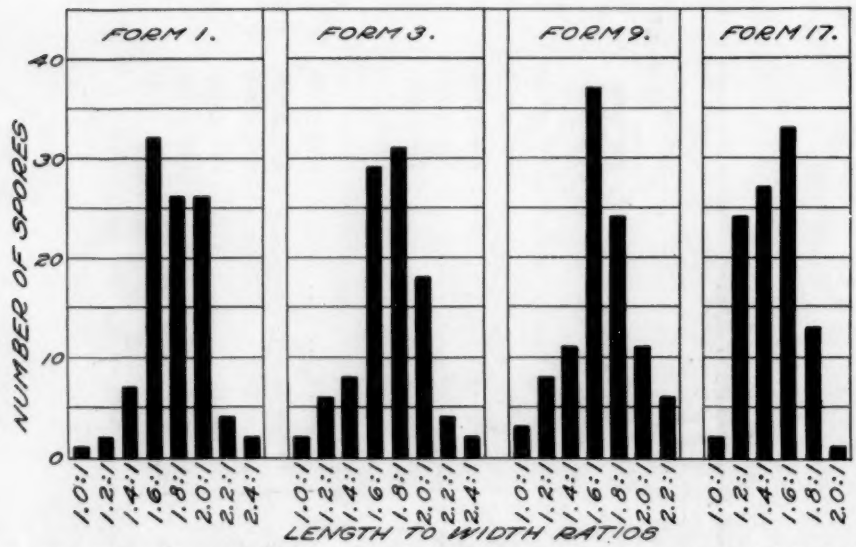


FIG. 27. Differences in urediniospores shape of monosporous cultures of four physiologic forms of *Puccinia graminis tritici*, grown on congenial host plants and under favorable environmental conditions.

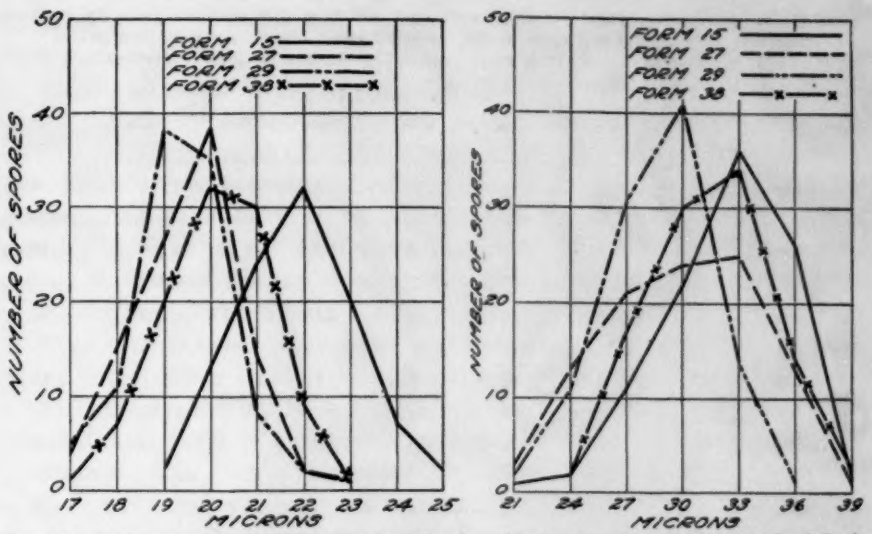


FIG. 28. Differences in urediniospore length of multisporous cultures of four physiologic forms of *Puccinia graminis tritici*, grown on congenial host plants and under uniform environmental conditions.

FIG. 29. Differences in urediniospore width of multisporous cultures of four physiologic forms of *Puccinia graminis tritici*, grown on congenial host plants and under uniform environmental conditions.

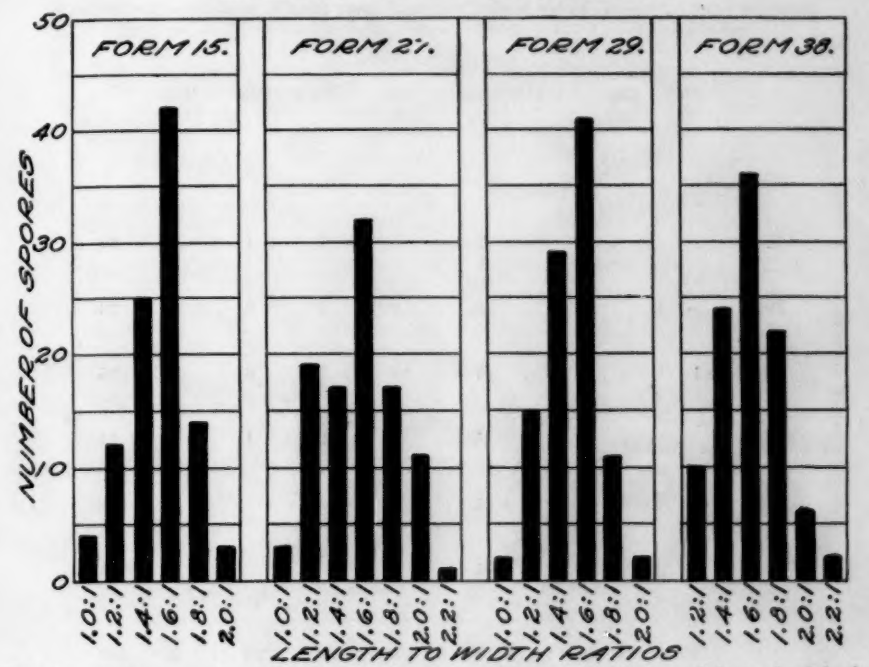


FIG. 30. Differences in urediniospore shape of multisporous cultures of four physiologic forms of *Puccinia graminis tritici*, grown on congenial host plants and under uniform environmental conditions.

TABLE 31.—*Correlation table for the length and width of 100 urediniospores of Puccinia graminis tritici, form 1. Spore width, subject; spore length, relative. Coefficient of correlation = − 0.557 ± 0.047; control of variability = 16.95 per cent*

SPORE WIDTH	24μ	27μ	30μ	33μ	36μ	39μ	42μ	
18μ					2	2	2	6
19μ				5	11	2	1	19
20μ			5	15	14	11	1	46
21μ		1	2	8	7			18
22μ			2	4				6
23μ	1		2	1				4
24μ			1					1
	1	1	12	33	34	15	4	100

SPORE LENGTH

TABLE 32.—*Correlation table for the length and width of 100 urediniospores of Puccinia graminis tritici form 3. Spore width, subject; spore length, relative. Coefficient of correlation = − 0.336 ± 0.060; control of variability = 5.81 per cent*

SPORE WIDTH	21μ	24μ	27μ	30μ	33μ	36μ	39μ	42μ	
17μ					1		2		3
18μ				2	5	7	1	2	17
19μ			1	3	8	8	3	1	24
20μ	1	1		7	13	7	6		35
21μ		2	2	5	2	2	1		14
22μ		1	1	1		2		1	6
23μ				1					1
	1	4	4	19	29	26	13	4	100

SPORE LENGTH

There is a greater variability in the length of urediniospores of form 3 than there is in those of either form 1, form 9, or form 17. The difference in length, although larger numerically than the difference in the width, perhaps is not significant statistically, as it exceeds its probable error only 3.17 times, the odds against the chance occurrence being about 30 to 1. But the difference between the mean widths of the two forms is 4.82 times greater than its probable error, and the odds are more than 800 to 1 that this difference is not due to random sampling. Therefore the difference in the spore width of the two forms very probably is significant. The shape of the urediniospores of form 3 is very much the same as that of the spores of form 1, their mean ratios being quite similar: $1.722 \pm 0.018 : 1$ as compared with $1.768 \pm 0.017 : 1$. Both forms have an equal number of elliptical urediniospores, but form 3 has a much greater proportion of spheroidal spores. Also there is a considerable greater variability in the shape of urediniospores of form 3 than there is in those of form 1. The correlation coefficient for the two diameters of form 3 is 0.336 ± 0.060. The morphogenic process is affected by one of the diameters to the extent of only 5.81 per cent, almost two-thirds less than in the case of form 1.

P. graminis tritici form 9.—Form 9 (Table 33) has shorter as well as narrower spores than either form 1 or form 3, measuring $31.35 \pm 0.23 \times$

TABLE 33.—*Correlation table for the length and width of 100 urediniospores of Puccinia graminis tritici form 9. Spore width, subject; spore length, relative. Coefficient of correlation* $= -0.522 \pm 0.049$; *control of variability* $= 14.71$ *per cent*

SPORE WIDTH	SPORE LENGTH 21μ	24μ	27μ	30μ	33μ	36μ	39μ	
16μ				2				2
17μ				1		5	1	7
18μ				8	10	5		23
19μ	1		3	11	9	5	1	30
20μ			4	9	8	2		23
21μ			6	3				9
22μ		2	1	1	1			5
23μ		1						1
	1	3	14	35	28	17	2	100

19.17 ± 0.09 μ. The differences in the mean length and mean width between the urediniospores of form 9 and form 1 are 10.69 and 8.17 times greater than their respective probable errors and undoubtedly are significant in both cases. The differences in these means between forms 9 and 3 exceed 6.33 and 3.75 times their respective probable errors, certainly a significant difference in length, but perhaps not in width. The urediniospores of form 9 are mostly ellipsoid and subglobose; the mean length-to-width ratio (1.656 ± 0.017 : 1) being lower than that of either of the two forms mentioned above, but the variability in shape is greater than that of form 1 but somewhat smaller than that of form 3. The correlation between the long and short dimensions is negative, the correlation coefficient approaching that of form 1, namely, − 0.522 ± 0.049. The growth of one diameter as affected by the other amounts to 14.71 per cent.

P. graminis tritici form 17.—The shape of the urediniospores of form 17 (Table 34) is more characteristic than their size, there being a preponder-

TABLE 34.—*Correlation table for length and width of 100 urediniospores of Puccinia graminis tritici form 17. Spore width, subject; spore length, relative. Coefficient of correlation = − 0.397 ± 0.057; control of variability = 8.22 per cent*

SPORE WIDTH	SPORE LENGTH 21μ	24μ	27μ	30μ	33μ	36μ	
16μ					1		1
17μ				1			1
18μ					4		4
19μ		1	2	7	6		16
20μ		4	6	13	11	2	36
21μ	1	1	10	16	2		30
22μ		1	6	3			10
23μ			1				1
24μ			1				1
	1	7	26	40	24	2	100

ance of subglobose and spheroidal individuals. Compared with the first three forms, just discussed, there is a marked and significant reduction in the mean length of the urediniospores of form 17. This reduction ranges from $1.80 \pm 0.30\,\mu$ to $5.22 \pm 0.29\,\mu$. The mean width, though, is almost identical with that of spores of form 1 but significantly different from the mean width of spores of forms 3 and 9. The dimensions of the urediniospores of form 17 are $29.55 \pm 0.19 \times 20.26 \pm 0.08\,\mu$, and the mean length-to-width ratio is $1.468 \pm 0.014 : 1$. There are more spheroidal urediniospores in this form than in the other three monosporous forms combined. The coefficient of correlation (-0.397 ± 0.057) is more like that of form 3, but the per cent of variability, 8.22 per cent, is somewhat larger than in form 3 and much smaller than in forms 1 and 9.

P. graminis tritici form 15.—Inasmuch as form 15 (Table 35) and the subsequent forms were cultured under different conditions than the forms discussed above, it would not seem justifiable to compare the various members comprising these two groups. The present investigation has shown, however, that the urediniospores cultured outside of the spore cages generally were considerably smaller than those cultured within (See tables 18–21 and figures 10–12). With this in mind it will be interesting to note that the

TABLE 35.—*Correlation table for length and width of 100 urediniospores of Puccinia graminis tritici form 15. Spore width, subject; spore length, relative. Coefficient of correlation* $= -0.357 \pm 0.059$; *control of variability* $= 6.59$ *per cent*

SPORE WIDTH	SPORE LENGTH 21μ	24μ	27μ	30μ	33μ	36μ	39μ	
19μ						2		2
20μ			1	1	6	4	1	13
21μ	1		1	5	7	9	1	24
22μ		1	3	5	17	6		32
23μ			3	8	4	5		20
24μ		1	2	3	1			7
25μ			1		1			2
	1	2	11	22	36	26	2	100

urediniospores of form 15, although developed in an open compartment, were much broader than those of any other form studied, whether cultured in this way or otherwise. The urediniospores of form 15 have a mean length and width of 32.28 ± 0.23 and $21.84 \pm 0.08\,\mu$, respectively. The excess in the mean width of these spores over those of the other forms ranges from $1.58 \pm 0.11\,\mu$ to $2.67 \pm 0.12\,\mu$, these differences being from 14.36 to 22.25 times greater than their respective probable errors and obviously really significant. The mean ratio of length-to-width of the urediniospores of form 15 is $1.518 \pm 0.015 : 1$, only slightly larger than the ratio for form 17, notwithstanding the marked difference in the spore size of these two forms. However, form 15 possesses fewer spheroidal and more subglobose spores than does form 17. Both forms have approximately the same number of ellipsoid urediniospores and neither one has any elliptical spores. The correlation coefficient of form 15 (-0.357 ± 0.059) is not greatly different from that of form 17; nor is the effect on the morphogenic process of the two forms at great variance, 6.59 per cent for form 15 and 8.22 per cent for form 17.

P. graminis tritici form 27.—The urediniospores of form 27 (Table 36) averaging $29.94 \pm 0.28 \times 19.53 \pm 0.08\,\mu$, are both shorter and narrower than

TABLE 36.—*Correlation table for length and width of 100 urediniospores of Puccinia graminis tritici form 27. Spore width, subject; spore length, relative. Coefficient of correlation* $= -0.295 \pm 0.062$; *control of variability* $= 4.49$ *per cent*

SPORE WIDTH	21μ	24μ	27μ	30μ	33μ	36μ	39μ	
	SPORE LENGTH							
17μ	1	1	1		1			4
18μ		1	1	2	5	5	1	15
19μ		2	4	6	9	5		26
20μ	2	4	7	12	10	3		38
21μ		4	7	3				14
22μ			1	1				2
23μ		1						1
	3	13	21	24	25	13	1	100

those of form 15. There is a difference of $2.34 \pm 0.36\,\mu$ in length and $2.31 \pm 0.11\,\mu$ in width. These differences undoubtedly are highly significant, as they are 6.50 and 21.00 times greater than their respective probable errors. The mean length-to-width ratio of form 27 ($1.556 \pm 0.018 : 1$) is but slightly and evidently not significantly greater than that of form 15. But form 27 has a greater proportion of spheroidal and ellipsoid-elliptical spores, and fewer subglobose individuals. The urediniospores of form 27 are the most variable in size and shape of all the stock forms. There is a considerably lower correlation coefficient (-0.295 ± 0.062) for the length and width of the uredinospores of form 27; and the per cent of variability controlled by this correlation is only 4.49 per cent, about one-third less than in the case of form 15.

P. graminis tritici form 29.—Form 29 (Table 37) has the smallest and least variable urediniospores of the four forms cultured from multisporous stock material. They average $28.71 \pm 0.19\,\mu$ in length and $19.40 \pm 0.07\,\mu$ in width, and differ significantly in both dimensions from the spores of form 15 and form 38. The difference in the mean length between the urediniospores of form 29 and form 27 is only $1.23 \pm 0.34\,\mu$, and exceeds its probable error 3.62 times, which may or may not be ascribed to a mere

TABLE 37.—*Correlation table for length and width of 100 urediniospores of Puccinia graminis tritici form 29. Spore width, subject; spore length, relative. Coefficient of correlation* $= -0.259 \pm 0.063$; *control of variability* $= 3.41$ *per cent*

SPORE WIDTH	SPORE LENGTH 21μ	24μ	27μ	30μ	33μ	36μ	
17μ		1	1	2	1		5
18μ			1	6	3	1	11
19μ	1	3	13	15	6		38
20μ		6	11	14	4		35
21μ	1		3	4			8
22μ		1	1				2
23μ			1				1
	2	11	31	41	14	1	100

fluctuation of sampling. There certainly does not seem to be any significant difference in the mean width of these two forms; but it may be there after all, and probably could have been demonstrated had the samples been considerably larger. In general, however, forms 29 and 27 are rather indistinguishable in size. On the other hand, the difference in size is very striking when the urediniospores of form 29 are compared with those of form 15, differing in mean length by $3.57 \pm 0.30\,\mu$ and in mean width by $2.44 \pm 0.11\,\mu$. In shape, the urediniospores of form 29 are very similar to those of form 15. Approximately, there are as many spheroidal, subglobose, and ellipsoidal spores in one form as in the other. Neither of the two forms possesses truly elliptical spores, *i.e.*, those which are more than twice as long as they are broad and both forms have almost identical mean

TABLE 38.—*Correlation table for length and width of 100 urediniospores of Puccinia graminis tritici form 38. Spore width, subject; spore length, relative. Coefficient of correlation* $= -0.003 \pm 0.067$; *control of variability* $= 0.05$ *per cent*

SPORE WIDTH	SPORE LENGTH 24μ	27μ	30μ	33μ	36μ	39μ	
17μ		1					1
18μ	1		1	3		2	7
19μ		1	3	10	5	1	20
20μ		6	10	11	5		32
21μ	1	6	10	9	4		30
22μ		3	5	1			9
23μ			1				1
	2	17	30	34	14	3	100

length-to-width ratios, namely, $1.500 \pm 0.014 : 1$ in the case of form 29, and $1.518 \pm 0.015 : 1$ in the case of form 15. There is another decline in the correlation coefficient (-0.259 ± 0.063) between the length and width of the urediniospores, with a corresponding reduction in the variability controlled by the correlation, which in this case amounts to only 3.41 per cent.

P. graminis tritici form 38.—Form 38 (Table 38) apparently is significantly different from form 27 and form 29 in the dimensions of both diam-

eters of its urediniospores, which average $31.50 \pm 0.22 \times 20.14 \pm 0.08\ \mu$, and is decidedly different from form 15 in spore width only. No truly spherical individuals were observed among the urediniospores of form 38. Some 10 per cent were spheroidal, but the majority were subglobose; about one-third were ellipsoid, and only a very few were elliptical. The ratio of length-to-width ($1.592 \pm 0.015 : 1$) is not significantly different from that of form 27 but definitely higher than in either form 15 or form 29. The long and short diameters of form 38 appear to be uncorrelated (-0.003 ± 0.067) but not necessarily independent. The control of variability exercised by this correlation is practically nil, viz., 0.05 per cent.

The mean length-to-width ratios, calculated by the ordinary mathematical processes in which all of the individuals concerned were taken into consideration, were compared with the quotients obtained by dividing the mean lengths established for certain populations by their corresponding mean widths. The probable errors of the quotients thus procured were computed by the formula given by Mellor (19) and quoted elsewhere in this paper. As may be gathered from table 39, no significant differences were found between the mean ratios and the ratios of the means, although such might conceivably exist and perhaps could have been demonstrated had many more cases been studied. However, it is quite possible that ratios obtained from a division of mean lengths by mean widths are, in fact, identical with the mean ratios determined by the regular method. But

TABLE 39.—*Comparison of the mean length-to-width ratios of certain physiologic forms of Puccinia graminis tritici determined by mathematical processes and the quotients obtained from dividing the mean length of each of these forms by the respective mean width*

Physiologic forms	Mean ratios of length-to-width calculated from all individuals concerned	Quotients computed by dividing each mean length by its mean width	Difference between ratios and corresponding quotients	Difference divided by respective probable error
1	1.768 ± 0.017	1.726 ± 0.013	0.042 ± 0.021	2.00
3	1.722 ± 0.018	1.714 ± 0.016	0.008 ± 0.024	0.33
9	1.656 ± 0.017	1.635 ± 0.014	0.021 ± 0.022	0.95
15	1.518 ± 0.015	1.478 ± 0.012	0.040 ± 0.019	2.11
17	1.468 ± 0.014	1.459 ± 0.011	0.009 ± 0.018	0.50
27	1.556 ± 0.018	1.533 ± 0.016	0.023 ± 0.024	0.96
29	1.500 ± 0.014	1.480 ± 0.011	0.020 ± 0.018	1.11
38	1.592 ± 0.015	1.564 ± 0.013	0.028 ± 0.020	1.40

even in such event the former method is not very helpful where shape of objects is under consideration. The quotient, at best, is only an abstract figure representing the arithmetical mean of all the shapes of a population; it is never an index of what the prevailing shapes or the extremes are like. These can be learned only from the frequency distribution of the shapes of all the individuals of a given random sample, from which in turn the various constants are derived.

The results given in tables 27 to 38 and in figures 25 to 30 show in a convincing way that the physiologic forms of *P. graminis tritici* differ not only in parasitic behavior but in morphology as well, and that, although the morphology of the urediniospores of a particular form may vary under varying cultural conditions, when grown under identical conditions on congenial hosts the spores have a common shape and size and other identifying characteristics. Physiologic forms, therefore, can be identified on the basis of morphology, but their parasitic behavior on certain varieties of wheat is the most satisfactory means of identification.

TABLE 40.—*Average dimensions of urediniospores of eight physiologic forms of Puccinia graminis tritici compared with the dimensions recorded for the variety tritici at large*

Physiologic forms	Arithmetic means	
	Length	Width
1	34.77 ± 0.22	20.15 ± 0.08
3	33.63 ± 0.28	19.62 ± 0.08
9	31.35 ± 0.23	19.17 ± 0.09
15	32.28 ± 0.23	21.84 ± 0.08
17	29.55 ± 0.19	20.26 ± 0.08
27	29.94 ± 0.28	19.53 ± 0.08
29	28.71 ± 0.19	19.40 ± 0.07
38	31.50 ± 0.22	20.14 ± 0.08
Average arithmetic means for the 8 physiologic forms....	31.47 ± 0.46	20.01 ± 0.19
Arithmetic means for variety *tritici* as a whole (15)....	32.40 ± 0.19	19.79 ± 0.06
Difference in the two means..	0.93 ± 0.50	0.22 ± 0.20
Difference divided by P. E....	1.86	1.10

The morphologic differences between forms of the variety *tritici* appear to be as great as, or greater than, the differences between varieties within the species *P. graminis*. It is a fact, however, (or is it a mere coincidence?) that biometrically the mean averages of the eight physiologic forms herein described are clearly not significantly different from the grand means reported for the variety *tritici* as a whole (see table 40). The means previously given by the writer (15) for the variety *P. graminis tritici* are $32.40 \pm 0.19 \times 19.79 \pm 0.06\,\mu$. The averages of the means of the eight physiologic forms described above are $31.47 \pm 0.46 \times 21.01 \pm 0.19\,\mu$. The difference between the two sets of figures is $0.93 \pm 0.50 \times 0.22 \pm 0.20\,\mu$, a discrepancy which in all probability is within the limits of probable error due to random sampling.

There was no correlation between the differences in pathogenicity and the differences in morphometry of the physiologic forms studied.

Effect of Ecological Factors on Susceptibility of Wheat Varieties

It is common knowledge that stem rust epidemics are much more severe in some years than in others. The amount of rust which developed on the same varieties grown at different stations in any one year, or at the same station in different years, varied very considerably, even at those stations from which the same physiologic form or forms were isolated. This variation undoubtedly was due to a complexity of factors, such as the uneven quantitative distribution of the rust inoculum, the stage of development and general condition of the wheat varieties when infection first occurred, and the edaphic and climatic conditions under which the host plants were grown. Of course it also is possible that other physiologic forms were present in addition to those isolated, a fact which would have influenced the intensity of the rust epidemic at different places in different seasons.

Quantity of Inoculum

It is obvious that a sufficient number of rust spores must be present on the growing grains to give the fungus a start. The inoculum may come from infected barberries or from wind-blown, or overwintered, urediniospores, depending largely on the locality. In India, Australia, and Mexico, for instance,[7] and even in certain parts of the Southern United States (26) the stem rust can, and evidently does, go through the winter in the uredinial stage. On the other hand, rust spores may be blown for considerable distances (28); but in the Upper Mississippi Valley of the United States barberries play a very important, if not the most important, part in starting rust epidemics (26).

[7] LEVINE, M. N. The epidemiology of cereal rusts in general and of the black stem rust in particular. U. S. Dept. Agr., Bur. Plant Indus. Off. Cereal Invest. 78 p. 1919. [Mimeographed.]

Table 41 and figure 31 illustrate the difference in the severity of stem rust infection in two uniform rust nurseries at University Farm, St. Paul, during three consecutive years, 1921–1923. One nursery was located in the plant pathology plots (designated in the figure as "A"), where the rust epidemic was induced artificially; the other nursery was situated in the plant breeding or agronomy plots (designated in the figure as "B"), where the rust infection was allowed to take its natural course. The two nurseries were not half a mile apart and the climatic conditions therefore identical. The epidemics in both nurseries, as indicated by the greenhouse studies, evidently were due to physiologic forms capable of infecting the hard red spring wheat varieties equally well. Yet, each year the average percentage infection on these varieties was considerably higher in the pathology nursery than in the agronomy nursery.

TABLE 41.—*Estimated percentage of stem rust on nine varieties of hard red spring wheat grown in duplicate uniform rust nurseries at St. Paul, Minn., in the three years 1921–1923, inclusive*

Variety and C. I. number	Percentage of infection					
	Pathology nursery			Agronomy nursery		
	1921	1922	1923	1921	1922	1923
Haynes Bluestem 2874	50	80	25	T	60	25
Marquis 3641	40	80	30	T	50	35
Power Fife 3697	55	85	35	25	60	25
Ruby 6047	30	85	35	T	50	20
Kitchener 4800	80	75	45	20	50	40
Red Bobs 6255	40	80	40	15	50	30
Preston 3081	45	85	45	20	65	30
Kota 5878	T	2	2	0	T	5
Prelude 4323	40	35	35	10	10	12
Average	42.2	67.4	32.4	10.0	43.9	24.7

From the data recorded in table 41, it may be seen that in 1921 the average rust infection was more than four times higher in the pathology nursery than it was in the agronomy nursery (42.2 per cent against 10.0 per cent); in 1922, the ratio was slightly better than 1.5 to 1 (67.4 per cent as compared with 43.9 per cent); and, in 1923, it was somewhat higher than 1.3 to 1 (32.4 per cent in the pathology nursery and 24.7 per cent in the agronomy nursery). These differences are consistent and significant and apparently are due to the introduction of a greater quantity of initial inoculum in the pathology nursery each year.

While it may seem self-evident that plants which have been heavily inoculated will become more heavily rusted than those less heavily inoculated, the opinion is fairly general that there usually is sufficient inoculum

abroad in any season, provided other conditions are favorable, to cause heavy infection. However, the observations here cited indicate that only abundant inoculum early in the season is conducive to heavy rust attacks. But in addition to a copious supply of inoculum, climatic conditions must be favorable at the critical time to produce a heavy rust epidemic. The cool weather and the low relative humidity in May, 1923 (see table 42 and figure 31), evidently are responsible for the rather slight excess, only 7.7 per cent, in the average infection that year in the pathology nursery over that in the agronomy nursery.

Condition of Host Plants

Freeman and Johnson (11) found that plants inoculated from the time when the heads emerged from the boot until they were in full bloom rusted much more heavily than plants inoculated either before or after this stage of development. The observations in the uniform rust nurseries have shown that there is some correlation between the severity of infection on a given susceptible variety and its stage of development, when all other conditions were equal. The nursery at Madison, Wis., was visited twice in 1922, on July 14 and August 15, respectively. On July 14 there was an abundance of leaf rust, whereas stem rust was just beginning to develop. Most of the varieties were in the soft dough stage, but Prelude was approaching maturity; Ruby, Marquis, Kahla and Peliss were in the advanced hard dough stage, and Little Club was flowering.

During the next several weeks, weather conditions were favorable for rust development. The mean temperature for the intervening month was about 70° F., and precipitation was adequate. On August 15 the green plants of Kubanka, Arnautka, and Mindum were badly rusted; the percentage of infection on some individuals was as high as 100 per cent. But the mature plants remained free from rust and the average infection on each of these varieties as a whole was estimated to be about 45 per cent. Acme, Monad, and Pentad, which had had no rust whatever on July 14, had as much as 10 and 20 per cent on individual immature plants or young shoots, and averaged 12 per cent for each of these varieties, taken as a whole. Kahla and Peliss, as well as Marquis, Ruby, Kota and Prelude, apparently escaped the rust infection, having no more than from 3 to 5 per cent rust each. But the infection on Power, Kitchener, Red Bobs, and Preston ranged from 15 to 40 per cent with an estimated average of 20 per cent.

The greatest fluctuation in infection appeared on Haynes Bluestem, ranging from 0 to 100 per cent, depending on the degree of maturity of the individual plants. The average infection on this variety also was

TABLE 42.—*Prevailing weather conditions at St. Paul, Minn., during the growing seasons of 1921, 1922, and 1923, where duplicate uniform rust nurseries were operated in which, respectively, natural and artificial epidemics obtained*

Years and months	Temperature (degrees Fahrenheit)					Precipitation (in inches)			Mean relative humidity (percentages)			Weather (number of days)			Sunshine	
	Maximum	Minimum	Mean	Normal	Departure	Total	Normal	Departure	7 a. m.	Noon	7 p. m.	Rainy[a]	Clear	Cloudy	Per cent of possible	Departure from normal
1921																
May	69.1	50.6	59.8	58.2	+1.6	3.38	3.62	−0.24	76.1	53.1	54.0	15	9	12	55	− 3
June	82.8	64.2	73.5	67.1	+6.4	4.70	4.41	+0.29	74.4	52.7	53.9	6	12	6	69	+ 7
July	86.8	66.6	76.7	72.1	+4.6	2.39	3.40	−1.01	76.2	48.1	54.2	11	15	1	83	+12
August	80.0	59.9	70.0	69.5	+0.5	2.79	3.46	−0.67	80.7	52.4	53.5	7	10	2	72	+ 7
1922																
May	71.5	53.5	62.5	58.2	+4.3	2.48	3.62	−1.14	76.0	59.4	57.1	14	5	8	49	− 8
June	78.2	58.4	68.3	67.1	+1.2	4.61	4.41	+0.20	76.4	58.0	58.7	12	10	4	67	+ 5
July	78.5	59.2	68.8	72.1	−3.3	2.32	3.40	−1.08	80.9	56.4	50.7	7	9	5	62	− 8
August	82.5	61.6	72.0	69.4	+2.6	1.31	3.46	−2.15	80.1	49.7	52.9	7	11	3	70	+ 4
1923																
May	68.9	48.4	58.6	57.9	+0.7	2.28	3.62	−1.34	67.9	46.0	44.6	10	11	4	74	+17
June	80.2	59.8	70.0	67.1	+2.9	4.28	4.41	−0.13	79.8	58.7	58.4	13	12	2	77	+15
July	85.8	64.7	75.2	72.1	+3.1	2.51	3.40	−0.89	77.6	50.5	51.7	7	15	2	84	+14
August	76.7	57.1	66.9	69.4	−2.5	1.92	3.46	−1.54	78.9	50.9	52.5	10	7	5	65	− 1

[a] Number of days on which 0.01 inch, or more, of precipitation occurred.

estimated to be about 45 per cent. Thirty per cent rust developed on Little Club. No rust whatever could be found on Vernal or Khapli. Form 21 alone was isolated from collections made on both visits. It would appear

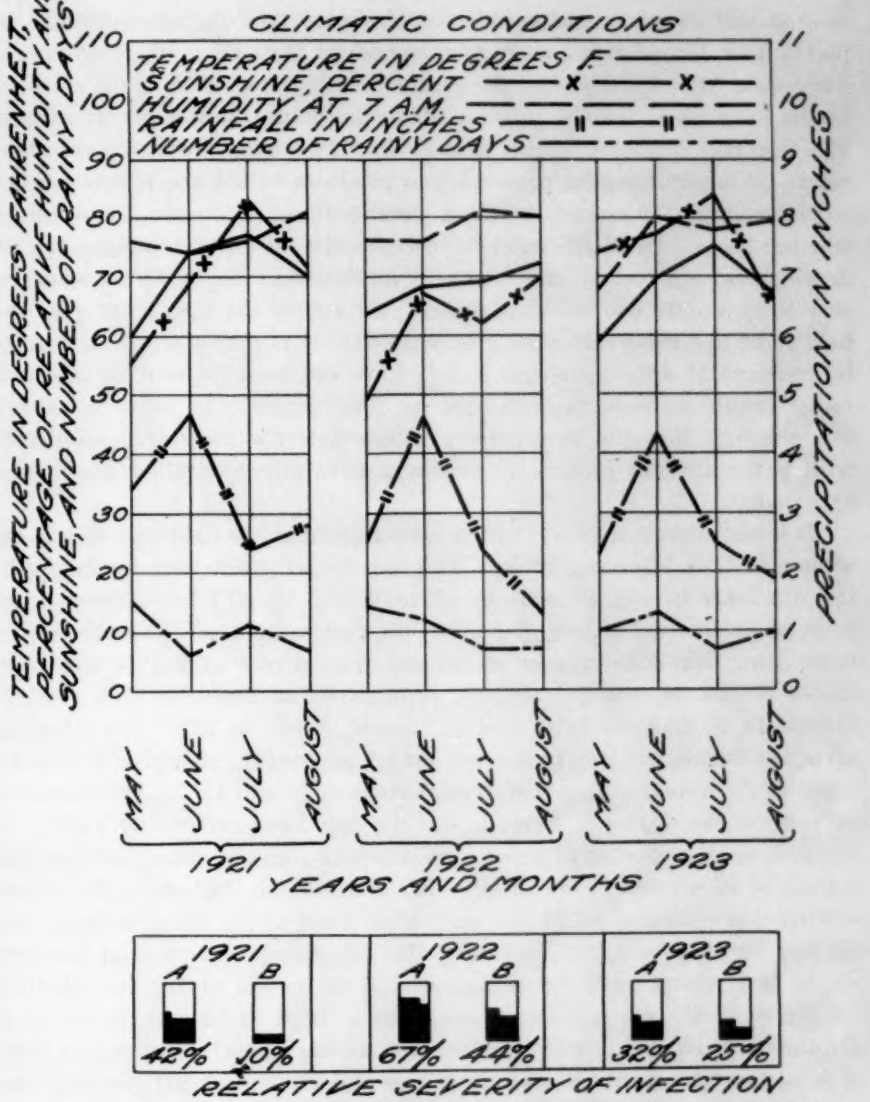

CLIMATIC CONDITIONS
TEMPERATURE IN DEGREES F.
SUNSHINE, PERCENT
HUMIDITY AT 7 A.M.
RAINFALL IN INCHES
NUMBER OF RAINY DAYS
TEMPERATURE IN DEGREES FAHRENHEIT, PERCENTAGE OF RELATIVE HUMIDITY AND SUNSHINE, AND NUMBER OF RAINY DAYS
PRECIPITATION IN INCHES
0 10 20 30 40 50 60 70 80 90 100 110
0 1 2 3 4 5 6 7 8 9 10 11
MAY JUNE JULY AUGUST
1921
1922
1923
YEARS AND MONTHS
A B
42% 10%
67% 44%
32% 25%
RELATIVE SEVERITY OF INFECTION

FIG. 31. Prevailing weather conditions and relative severity of stem rust infection in duplicate uniform rust nurseries, located respectively in the plant pathology (A) and plant breeding (B) plots at St. Paul, Minn., during three consecutive years, 1921–1923, inclusive.

from this and similar observations that, other conditions being equal, the degree of maturity of susceptible varieties at the time infection first takes place probably determines the severity of the rust attack on these varieties.

While the results obtained can be interpreted differently, there seems to be sufficient observational evidence to indicate that the susceptibility of plants does depend to a considerable extent on their stage of development. They seem to be quite susceptible in the seedling stage and again at about heading-out time. In the jointing stage the plants show more resistance. Whether this resistance is due to rapidity of growth, morphological characters, or to physiological processes and products within the plants can not be determined, of course, by field observations. In order to ascertain whether the apparent difference in susceptibility at different stages of host development is a real difference or only an apparent one, it would be necessary to have only one variable, namely, the age of the host plant. In the field there are many variables. It is possible that plants which appear to be resistant at different stages merely have not been exposed to infection under conditions most favorable for its development. In order to answer this question, it would be necessary to correlate the stage of development with environmental factors by means of carefully controlled greenhouse experiments.

It is well known that early-sown spring grain is less liable to suffer from stem rust than late-sown grain. This was brought out very strikingly in the duplicate sowing experiment of 1919 and 1920. The varieties were sown at an interval of two weeks, but the rust estimates were made on the same date. The difference in the amount of stem rust, as may be seen from tables 43 and 44, was particularly pronounced at Amarillo, Tex., and at Highmore, S. Dak., in 1919; and at Lincoln, Nebr., in 1920. At Amarillo all of the durum varieties in the first sowing escaped the rust attack entirely, while in the second sowing there was as much as 10 and 15 per cent infection on some of the durums. Prelude was the only hard red spring variety in the first sowing which had 3 per cent stem rust; all the other varieties had a trace of stem rust or none at all. The infection on Prelude in the second sowing was estimated as 60 per cent, while some of the other varieties had 65 and 70 per cent. At Highmore, the infection on the durum varieties in the first sowing was 5 per cent or less, in the second sowing the infection on the normally susceptible varieties was as high as 65 and 80 per cent. On the hard red spring wheats in the first sowing the infection ranged from 5 to 10 per cent; in the second sowing as high as 95 and 100 per cent rust appeared. A similar situation prevailed at Lincoln in 1920.

There were only slight differences in the severity of rust attack on the varieties of the two sowings at Lincoln, Nebr., in 1919, and at St. Paul,

TABLE 43.—*Percentages of stem rust on varieties of wheat grown in 1919 at seven uniform rust nurseries where duplicate sowings of the varieties were made at an interval of two weeks*

Class, variety, and C. I. number	Sowings at experiment stations													
	Akron, Colo.		Amarillo, Tex.		Brookings, S. Dak.		Highmore, S. Dak.		Lincoln, Nebr.		Newell, S. Dak.		St. Paul, Minn.	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Durum														
Kubanka 1440	T	10	0	10	25	40	5	25	10	15	0	5	T	T
Kubanka 2094	T	8	0	2	25	25	5	65	3	5	5	5	T	T
Kubanka 4063	T	10	0	10	30	65	5	65	10	65	5	5	T	T
Arnautka 4064	T	8	0	15	40	65	5	65	15	50	5	5	T	65
Arnautka 6236	T	8	0	10	40	65	5	80	15	25	10	25	T	T
Mindum 5296	.	2	0	2	30	55	5	25	3	5	5	5	T	T
Acme 5284	.	T	0	T	1	0	1	5	2	2	5	20	T	T
Monad 3320	.	T	0	1	1	0	1	5	2	3	5	5	0	0
Pentad 3322	.	0	0	0	1	0	1	0	T	0	0	5	0	0
Hard Red Spring														
Haynes 2874	T	35	T	65	65	100	10	100	90	100	25	40	25	50
Marquis 3641	10	15	T	65	50	85	10	70	65	85	25	50	25	40
Power 3697	T	15	T	55	65	100	10	95	85	90	25	40	25	60
Ruby 6047	T	20	T	70	25	100	5	20	85	65	10	65	T	25
Preston 3081	T	25	T	70	65	95	10	90	90	90	25	40	20	80
Kota 5878	T	T	0	1	25	5	5	T	2	5	25	5	T	T
Prelude 4323	T	15	3	60	25	100	5	15	85	65	10	25	15	30
Kubanka × Haynes 4788	5	10	T	40	50	100	10	40	65	50	10	50	15	30
Kubanka × Preston 4789	T	10	0	25	40	100	10	25	40	40	25	65	5	30
Emmer														
Vernal 3686	T	T	0	0	3	0	1	1	0	T	0	2	0	0
Khapli 4013	T	T	0	0	5	0	0	1	0	0	0	0	0	0
Average infection for each experiment	1.2	9.8	0.2	25.1	30.6	55.0	5.5	39.6	33.4	38.0	11.0	23.1	5.9	19.4

TABLE 44.—*Percentage of stem rust on varieties of wheat grown in 1920 at four uniform rust nurseries where duplicate sowings of the varieties were made at an interval of two weeks*

Class, variety and C. I. number	Sowings at experiment stations							
	Indian Head, Sask.		Lincoln, Nebr.		St. Paul, Minn.		Saskatoon, Sask.	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Durum								
Kubanka 1440	35	40	1	5	60	95	10	30
Kubanka 2094	35	35	2	10	45	100	10	30
Kubanka 4063	40	40	1	5	70	95	15	30
Arnautka 4064	35	35	1	5	95	95	10	30
Arnautka 6236	40	40	1	5	70	95	7	30
Mindum 5296	35	35	1	5	65	95	6	10
Acme 5284	15	25	1	4	40	25	3	7
Monad 3320	15	25	1	4	55	25	3	7
Pentad 3322	3	3	1	4	45	30	1	3
Hard Red Spring								
Haynes 2874	35	55	4	33	90	100	25	40
Marquis 3641	45	50	3	23	95	100	20	25
Power 3697	40	65	4	25	100	100	20	40
Ruby 6047	45	65	1	40	85	85	20	40
Preston 3081	45	65	4	33	95	100	25	35
Kota 5878	30	35	1	4	25	40	3	1
Prelude 4323	40	55	4	40	90	95	25	35
Kubanka × Haynes ... 4788	40	65	1	5	100	95	20	40
Kubanka × Preston .. 4789	40	65	1	4	95	100	25	35
Emmer								
Vernal 3686	1	1	1	2	10	15	0	0
Khapli 4013	1	1	0	0	3	5	1	1
Average infection for each experiment	30.8	40.0	1.5	12.8	66.7	74.5	12.5	23.5

Minn., in 1920. However, a comparison of the average stem rust infection on all the varieties of wheat and emmer grown at seven uniform rust nurseries in 1919, and four in 1920, showed a significant difference in the effect of the rust attack in the earlier and later sowings. Calculations by the aid of Student's method (1, 2) reveal that the odds are very great, that these differences are genuine and not due to experimental or observational error (See table 45).

TABLE 45.—*Comparison of severity of stem rust infection in uniform rust nurseries where duplicate sowings of wheat varieties were made at an interval of two weeks*

Results	Year	
	1919	1920
Number of trials	7	4
Average infection on early sowing	12.54	27.88
Average infection on later sowing	30.00	37.70
Mean difference (m. d.)	17.46	9.83
Standard deviation (σ)	9.77	1.42
z (m. d. $\div \sigma$)	1.79	6.90
Odds against chance occurrence of difference.....	434 : 1	1666 : 1

It is not possible to ascertain from the climatological data given in tables 46 and 47 that weather conditions were the governing factor in causing the marked difference in reaction of the varieties to rust attack in the early and late sowings. Apparently it is not a question of disease escape because of changes in the host plants incident to early maturity.

TABLE 46.—*Prevailing weather conditions during growing season of 1919 at seven uniform rust nurseries in the United States where duplicate sowings of the wheat varieties were made at an interval of two weeks*

Experiment stations and months	Temperature (degrees F.)		Precipitation (in inches)		Weather (number of days)		
	Mean	Departure from normal	Total	Departure from normal	Rainy[a]	Clear	Cloudy
Akron, Colo.							
May	55.7	.....	1.59	−1.19	6	10	0
June	65.4	.....	2.21	−0.37	8	17	5
July	...	.....	...	.....	..	..	..
August	73.4	.....	0.44	−1.49	5	12	5
Amarillo, Tex.							
March	46.4	+1.4	1.73	+1.08	5	14	4
April	54.5	−0.1	2.56	+0.84	9	10	6
May	61.8	−2.5	2.08	−1.59	11	7	6
June	68.9	−3.1	2.94	−0.05	10	11	0
Brookings, S. Dak.							
May	56.4	+1.2	3.87	+0.63	11	15	7
June	68.6	+3.5	9.30	+5.64	16	9	16
July	73.6	+4.0	5.60	+3.15	11	15	1
August	68.6	+0.8	1.48	−1.33	4	15	0
Highmore, S. Dak.							
May	56.2	−0.4	6.63	+4.21	10	16	8
June	68.6	+0.9	1.90	−1.26	9	16	9
July	74.7	+1.8	2.65	+0.18	7	17	4
August	71.8	+0.4	0.82	−1.56	5	18	3
Lincoln, Nebr.							
May	60.7	−2.2	3.83	−0.42	9	8	10
June	73.0	+1.4	4.99	+0.67	13	6	10
July	82.2	+5.8	0.38	−3.45	4	21	3
August	74.8	+0.5	4.67	+0.96	8	11	10
Newell, S. Dak.							
May	56.8	+3.3	0.65	−2.12	6	19	7
June	70.3	+4.8	0.18	−2.44	2	14	1
July	78.0	+6.4	2.90	+0.63	7	11	2
August	73.0	+3.0	0.77	−0.51	5	26	0
St. Paul, Minn.							
May	57.5	−0.2	2.17	−1.49	8	11	6
June	69.1	+2.6	4.75	−0.01	13	9	12
July	72.7	+1.5	6.15	−4.07	11	14	3
August	68.2	−1.0	1.46	−1.24	10	14	2

[a] Number of days on which 0.01 inch, or more, of precipitation occurred.

The rust inoculum increases in geometrical progression. It is quite obvious, therefore, that those varieties which mature early are likely to escape the heaviest inoculation, while those which mature late are quite likely to be subjected to it. The difference between the amount of rust on early maturing varieties and later maturing varieties, therefore, probably is not due to the stage of development of the host plants as much as to the quantity of inoculum.

TABLE 47.—*Prevailing weather conditions during growing season of 1920 at four uniform rust nurseries in the United States and Canada where duplicate sowings of the wheat varieties were made at an interval of two weeks*

Experiment stations and months	Temperature (degrees F.)		Precipitation (in inches)		Weather (number of days)		
	Mean	Departure from normal	Total	Departure from normal	Rainy[a]	Clear[b]	Cloudy
Indian Head, Sask.							
May	51.0	+1.0	1.46	−0.52	4	221	5
June	58.0	−1.0	2.10	−1.88	6	241	2
July	65.0	+1.0	5.24	+2.78	3	300	2
August	64.0	+3.0	1.42	−0.70	7	266	3
Lincoln, Nebr.							
May	61.0	−1.9	3.77	−0.48	14	2	17
June	73.0	+1.4	2.05	−2.27	7	11	8
July	76.6	+0.2	3.80	−0.03	10	14	3
August	71.8	−2.5	3.69	−0.02	7	16	7
St. Paul, Minn.							
May	59.0	+0.8	2.34	−1.65	7	13	7
June	68.0	+0.6	9.64	+3.35	14	7	7
July	70.2	−1.9	1.35	−2.05	8	16	4
August	69.2	−0.3	0.96	−2.50	6	19	4
Saskatoon, Sask.							
May	52.0	+2.0	1.43	−0.16	10	278	2
June	58.0	−1.0	0.99	−1.52	9	316	1
July	67.0	+5.0	2.24	−0.30	8	378	1
August	64.0	+4.0	2.72	+0.55	11	278	3

[a] Number of days on which 0.01 inch, or more, of precipitation occurred.

[b] For the Canadian stations the registered duration of sunshine is recorded in hours; for the American stations, the number of clear days per month are indicated.

Soil and Topography

There were two uniform rust nurseries in close proximity at Coon Creek, Minn., in 1923; one on sandy soil and the other on peat soil. The varieties on the sandy soil matured considerably earlier than the same varieties in the peat bog. In the sandy soil the plants were fully mature on July 21 when the rust notes were taken, while in the peat bog they were still in the dough stage on July 30. As will be noted from table 7, in spite

of the fact that infection was evidently caused by the same physiologic forms, there was more rust in the peat nursery than in the sand nursery. This observation would seem to confirm the conclusions of other investigators (27, 14) that conditions which are conducive to a succulent growth of the grain plants and the formation of collenchymatous tissue also are favorable to abundant production of stem rust. Of course it must be borne in mind that a difference in the soil nutrition, relative humidity, and amount of dew in the two nurseries may have been the factors which caused the differences in the severity of the rust infection.

Prevailing Weather Conditions

A careful study was made of the climatological data pertaining to the experiment stations at which uniform rust nurseries were operated[8] with the object of finding a possible correlation between weather conditions and severity of rust infection. For the sake of greater accuracy it was decided to limit this study in detail to those stations where the experiment was conducted in every year of the five-year period. St. Paul, Minn., and Fargo, N. Dak., therefore were selected to represent the Prairie Area, and Mandan, and Dickinson, N. Dak., and Akron, Colo., the Great Plains Area. The estimated rust percentages on five hard red spring wheat varieties grown at each of these stations in the five years, 1919–1923, inclusive, and the calculated annual average percentages are presented in table 48. In table 49 are recorded the climatological data for these localities, covering the growing seasons of the period under consideration A study also was made of the effect of the mean temperature and total precipitation during the last two months of the development of the wheat plant on the stem rust epidemic on three varieties of equally susceptible and uniformly maturing hard red spring wheat, grown at the different experiment stations during 89 nursery years. The results are summarized in tables 50–56, inclusive.

All the climatological data, unless otherwise stated, were obtained from the official records of the United States Weather Bureau and the Canadian Meteorological Service. In a few cases where no weather records were kept the data of the nearest meteorological station were used. The precipitation data for St. Paul, Minn., are those of University Farm; they were obtained from the Division of Soils. As the hard red spring wheat varieties, Haynes, Marquis, Power, Preston, and Kota, are practically equally susceptible under favorable conditions to all the physiologic forms

[8] Thanks are due to Mr. U. G. Purssell, Associate Meteorologist, Minnesota Climatological Section, Weather Bureau, United States Department of Agriculture, for his kindness in furnishing the American weather records; and to Sir Frederic Stupart, Director, Meteorological Service, Department of Marine and Fisheries, Canada, for the liberal supply of Canadian weather records.

TABLE 48.—*Percentage of stem rust on five varieties of hard red spring wheat grown at five typical uniform nurseries in the United States in the five years, 1919–1923, inclusive*

Stations and years	Varieties and rust percentages						
	Haynes C.I. 2874	Marquis C.I. 3641	Power C.I. 3697	Preston C.I. 3081	Kota C.I. 5878	Group average	5-yr. average
St. Paul, Minn. ...	.....	.....	.....	.....	.....	.....	53.2
1919	50	40	60	80	0	46.0	
1920	100	100	100	100	40	88.0	
1921	50	40	55	45	T	38.0	
1922	80	80	85	85	2	66.4	
1923	25	30	35	45	2	27.4	
Fargo, N. Dak. ...	.....	.....	.....	.....	.....	.....	77.4
1919	100	100	100	100	10	82.0	
1920	100	65	100	100	10	75.0	
1921	95	90	100	95	5	77.0	
1922	100	98	98	95	35	85.2	
1923	75	70	80	80	35	68.0	
Mandan, N. Dak. ..	.....	.....	.....	.....	.....	.....	37.1
1919	40	25	37	43	T	29.0	
1920	80	65	65	75	T	57.0	
1921	10	8	6	8	0	6.4	
1922	75	40	75	70	15	55.0	
1923	40	30	50	55	15	38.0	
Dickinson, N. Dak.	.....	.....	.....	.....	.....	.....	26.6
1919	0	0	0	0	0	0.0	
1920	22	16	17	20	1	15.2	
1921	12	5	5	3	T	5.0	
1922	75	55	80	80	20	62.0	
1923	75	20	75	75	10	51.0	
Akron, Colo.	.....	.....	.....	.....	.....	.....	22.8
1919	35	15	15	25	T	18.0	
1920	65	50	60	65	15	51.0	
1921	0	T	0	0	0	0.0	
1922	2	T	5	15	7	5.8	
1923	40	40	45	50	20	39.0	

isolated, their average percentage infection was chosen as the basis for comparison.

An examination of table 49 shows that neither atmospheric temperature alone, nor total precipitation alone, whether considered for the entire growing season or for each individual month separately, can account for the difference in the severity of rust infection. But a study of figures 32–36 reveals an apparent correlation in normal years between the combined mean temperature and total precipitation in the month of June and the amount of rust at the end of the growing season. This correlation is quite pronounced at each of the five stations studied in detail, except Fargo, where other factors seem to have exerted a profound influence on the development of the rust. This question will be discussed more fully later.

TABLE 49.—*Prevailing weather conditions, during the growing season, at five typical uniform rust nurseries in the five years, 1919–1923, inclusive*

Stations and years	Climatological data											
	Mean temperature, ° F.				Total precipitation in.				Number rainy days[a]			
	May	June	July	Aug.	May	June	July	Aug.	May	June	July	Aug.
St. Paul, Minn.												
1919	57.5	69.1	72.7	68.2	2.17	4.75	6.15	1.46	8	12	11	10
1920	59.0	68.0	70.2	69.2	2.34	9.64	1.35	0.96	7	14	8	6
1921	59.8	73.5	76.7	70.0	4.10	3.19	4.27	1.05	15	6	11	7
1922	62.5	68.3	68.8	72.0	2.86	6.76	1.73	1.55	14	12	7	7
1923	58.6	70.0	75.2	66.9	3.05	4.95	2.90	1.90	10	13	7	10
Fargo, N. Dak.												
1919	57.0	69.0	71.9	68.2	4.01	2.50	5.56	2.83	12	10	8	8
1920	55.6	64.8	68.9	68.4	2.53	5.89	2.92	1.33	11	14	8	7
1921	56.6	70.4	72.8	68.2	2.56	1.40	3.08	3.94	8	7	8	11
1922	59.5	65.6	67.3	71.4	3.94	2.93	1.65	0.74	13	8	8	7
1923	55.8	68.1	72.5	63.9	1.85	6.73	2.34	2.83	7	11	7	8
Mandan, N. Dak.												
1919	55.8	69.0	74.2	71.0	3.90	1.17	0.85	1.22	11	6	7	7
1920	56.4	65.4	71.4	70.6	1.72	1.63	2.68	1.80	8	11	7	5
1921	60.4	72.2	78.1	70.0	5.13	3.52	2.46	3.97	11	6	9	4
1922	57.8	66.0	66.6	72.4	2.05	3.43	3.17	0.31	17	11	10	5
1923	56.4	67.2	73.4	64.8	1.82	1.94	4.12	1.15	6	13	12	5
Dickinson, N. Dak.												
1919	54.6	69.9	73.8	69.8	2.49	0.52	0.53	0.59	11	4	5	6
1920	52.5	61.6	67.3	68.0	1.39	4.32	2.76	2.35	13	12	8	7
1921	51.0	69.2	71.0	66.7	1.78	3.09	1.61	2.73	10	8	7	5
1922	54.1	63.3	64.4	69.2	1.97	6.57	1.92	0.69	14	14	14	6
1923	52.4	65.3	70.0	63.1	1.46	4.49	4.67	0.82	9	8	10	9
Akron, Colo.												
1919	55.7	65.4	...	73.4	1.59	2.21	...	0.44	6	8	..	5
1920	...	64.1	71.4	67.0	...	4.89	4.72	1.45	..	11	6	8
1921	56.6	67.6	74.3	...	0.50	1.06	2.25	...	12	12	4	..
1922	56.5	68.4	71.6	75.0	3.69	1.43	3.24	1.24	11	6	12	9
1923	54.4	...	73.2	69.6	4.94	...	3.62	0.78	12	..	11	7

[a] Number of days on which 0.01 inch, or more, of precipitation occurred.

At St. Paul, Minn., (See table 49 and figure 32), in 1919, the total precipitation for June (4.75 inches) was a little more than one inch below the five-year average; the mean temperature (69.1° F.) was more than two and one-half degrees above normal. The rust infection on the five common wheat varieties was 46 per cent, or about 7 per cent lower than the average for the five years. In 1920, the precipitation in June (9.64 inches) was almost four inches above the average, while the mean temperature (68° F.) was only about half a degree above normal. There was an average of 88 per cent stem rust on the common wheats that year, or 35 per cent more than the five-year average. In 1921, very high temperature (73.5° F.) and very low precipitation (3.19 inches) prevailed in June and the rust infection was almost 15 per cent less than the five-year average. In 1922,

the mean temperature in June was only 1.2° above normal (68.3° F.) and the total precipitation was about one inch above the five-year average. The average rust infection was 66.4 per cent, or about 13 per cent more than the five-year average. In 1923, below average precipitation and rather high temperature in June were correlated with a fairly meager quantity of rust (27.4 per cent). Similar correlations, as may be seen from figures 34 and 35, respectively, are apparent at Mandan and Dickinson, N. Dak. In the case of Akron, Colo., the correlation is not so striking, although it is fairly definite. This may be due in part to the fact that the climatological data for this station are not quite complete, and estimated figures were substituted for the missing data.

At Fargo, N. Dak., we find no such correlations as we have found in the case of the other four stations. The heaviest average infection, 85.2 per cent, on the five common wheat varieties in the Fargo nursery occurred in 1922. The June temperature (65.6° F.) was 1.3° above normal and the precipitation was low (2.93 inches), being one inch below normal. In 1919, also there was a very heavy stem rust epidemic, averaging 82 per cent. This year the June conditions seemed even less favorable for rust development, namely, fairly high temperature (69° F.), 4.7° above normal, and fairly low precipitation (2.50 inches), about 1.5 inches below normal. In 1923, the temperature and rainfall conditions seemed to be very favorable for the development of stem rust, but this was the only year in which there was the least amount of rust at this station, namely, 68 per cent. In that year precipitation in June was very high (6.73 inches), about three inches above normal, and moderate temperature prevail (68.1° F.). There was 9 per cent more rust in 1921 than in 1923, although the conditions did not appear at all so favorable. The mean temperature in June was rather high for Fargo (70.4° F.), over 6° above normal, and the precipitation (1.40 inches) was almost 3 inches below normal. June of 1920 was much cooler than that of 1921 (64.8° F.) and the rainfall was considerably heavier (5.89 inches), yet the average amount of rust on the five common wheats was virtually the same in both years.

There is another interesting point about the Fargo situation. It will be observed from table 48 that the highest five-year average rust infection was at Fargo. The rust epidemic on the five hard red spring varieties was worst at Fargo each year of the investigation except 1920, when the infection at St. Paul exceeded that of Fargo by an average of 13 per cent. From the data at hand, it is difficult to ascertain definitely what other factors have contributed to this apparent anomaly. Of course wheat matures somewhat later at Fargo than at St. Paul, and the July conditions perhaps should be considered in preference to those of June. But this also

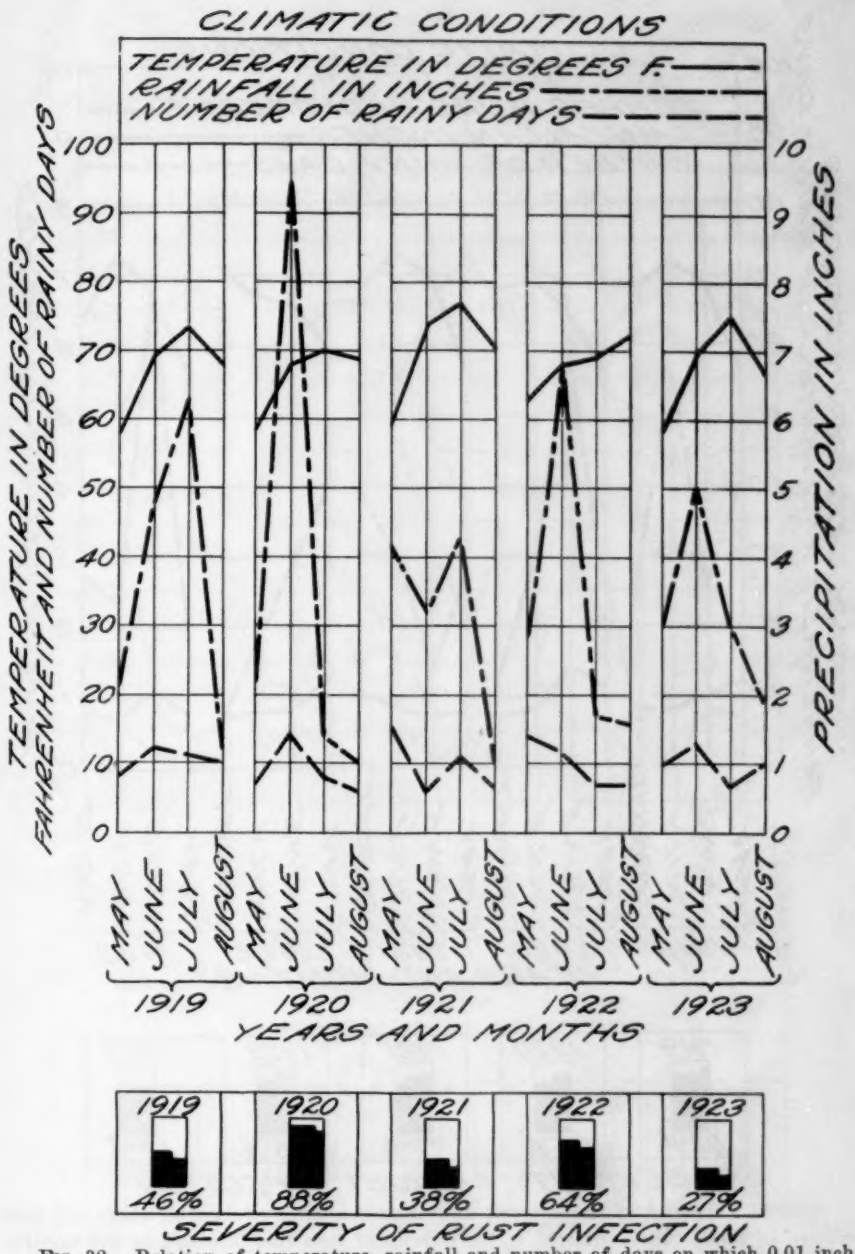


FIG. 32. Relation of temperature, rainfall and number of days on which 0.01 inch, or more, of precipitation occurred, to the severity of stem rust infection on five varieties of hard red spring wheat, grown in the uniform rust nursery at St. Paul, Minn., in the five years, 1919–1923, inclusive.

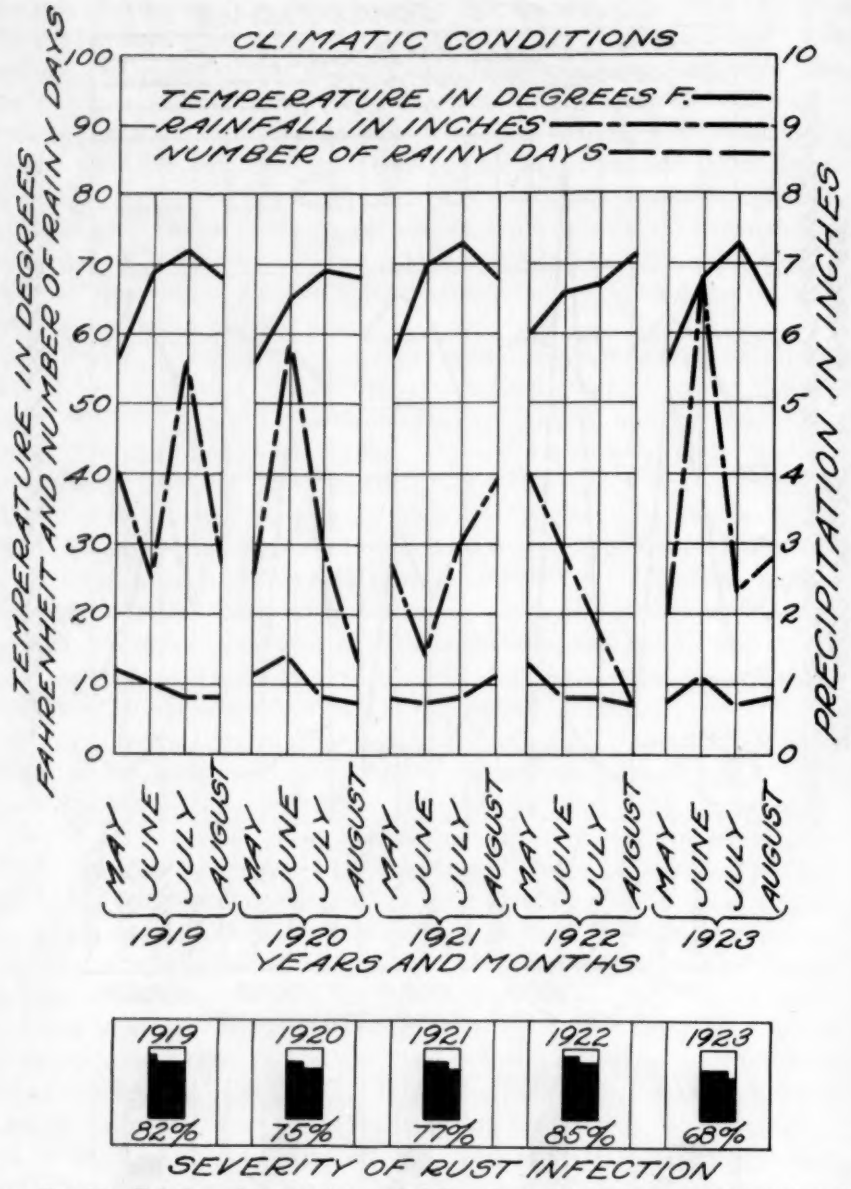


FIG. 33. Relation of temperature, rainfall, and number of days on which 0.01 inch, or more, of precipitation occurred, to the severity of stem rust infection on five varieties of hard red spring wheat, grown in the uniform rust nursery at Fargo, N. Dak., in the five years, 1919–1923, inclusive.

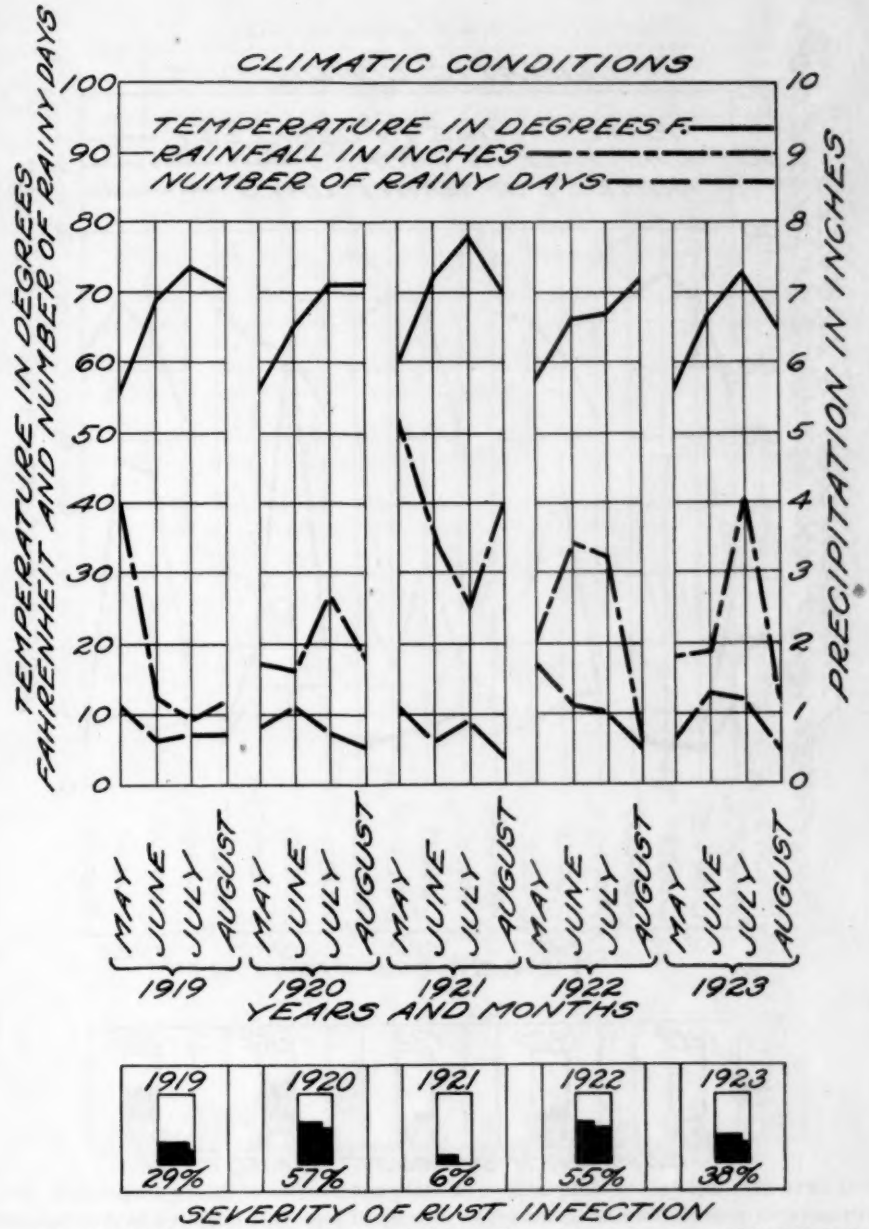


FIG. 34. Relation of temperature, rainfall, and number of days on which 0.01 inch, or more, of precipitation occurred, to the severity of stem rust infection on five varieties of hard red spring wheat, grown in the uniform rust nursery at Mandan, N. Dak., in the five years, 1919–1923, inclusive.

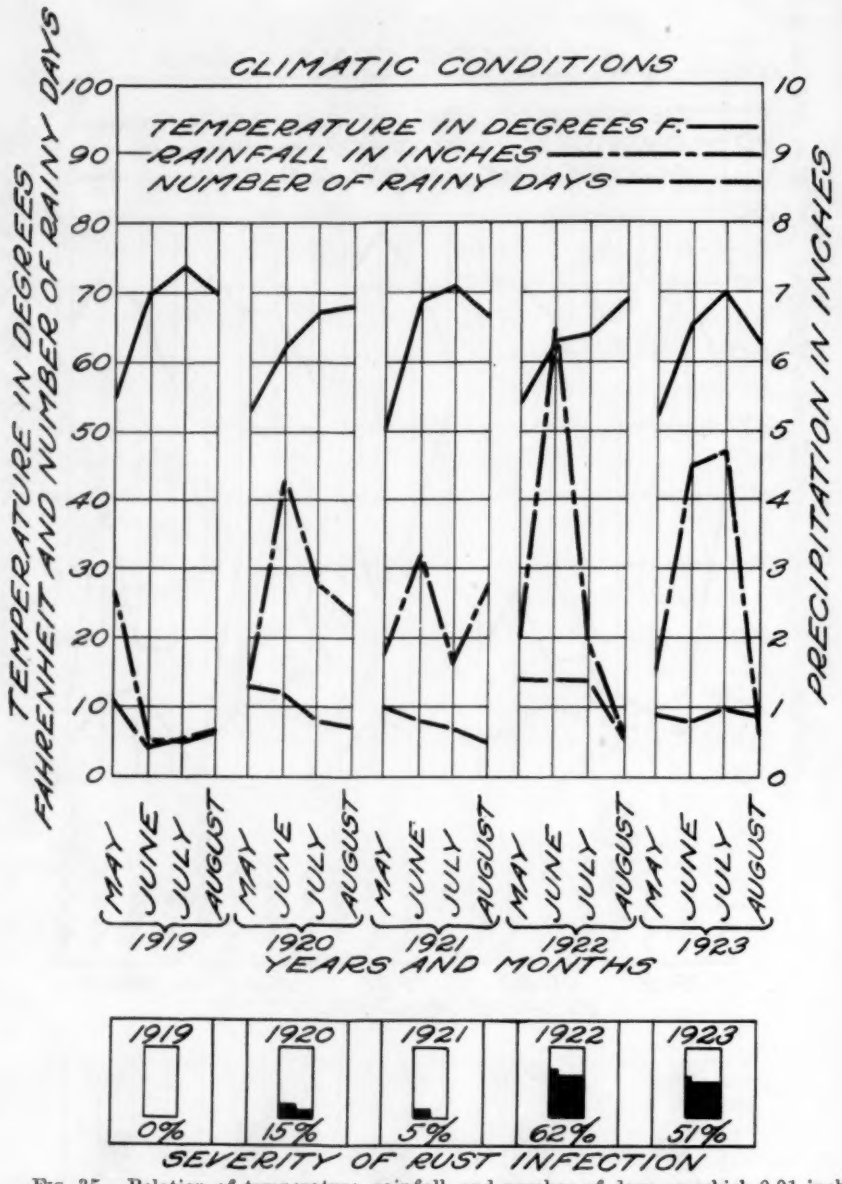


FIG. 35. Relation of temperature, rainfall, and number of days on which 0.01 inch, or more, of precipitation occurred, to the severity of stem rust infection on five varieties of hard red spring wheat, grown in the uniform rust nursery at Dickinson, N. Dak., in the five years, 1919–1923, inclusive.

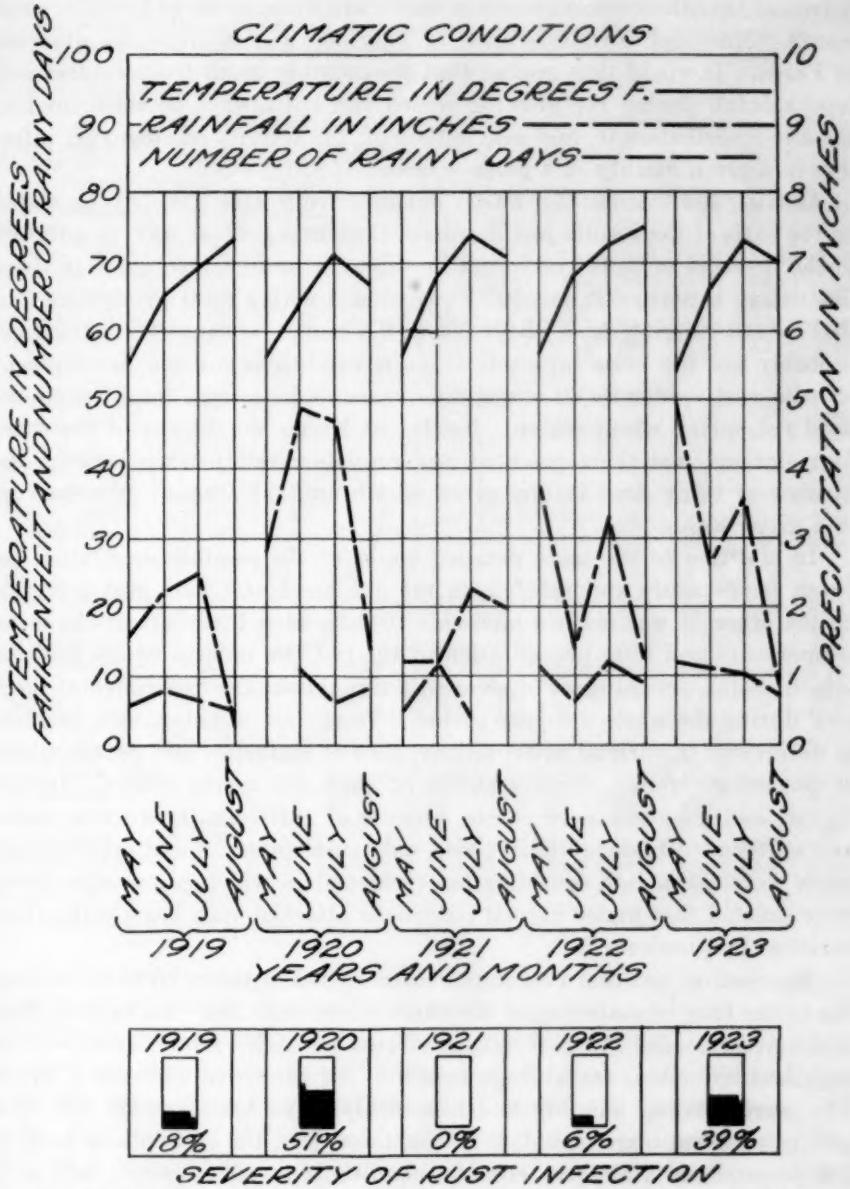


FIG. 36. Relation of temperature, rainfall, and number of days on which 0.01 inch, or more, of precipitation occurred, to the severity of stem rust infection on five varieties of hard red spring wheat, grown in the uniform rust nursery at Akron, Colo., in the five years, 1919–1923, inclusive.

is true of the other western stations, and there June seems to be the critical month. Moreover, a consideration of July does not improve the situation at Fargo. It would thus appear that the monthly mean temperatures and total rainfall during the growing season can not always be considered as the sole contributors to, and safe indices of, the severity of stem rust infection in a given locality in a given season.

Leaving a situation like Fargo out of consideration, it may be stated on the basis of the results just discussed that, in a general way, in addition to the presence of sufficient initial inoculum, a mean temperature in June fluctuating between 63° and 70° F., combined with a total precipitation in that month ranging from about 2.5 to 9.5 inches, adequately distributed, probably are the most favorable climatic conditions for the development of stem rust epidemics on susceptible varieties in certain localities in the hard red spring wheat region. Neither at Fargo, nor at any of the other four stations, was there observed any consistent relationship between the number of rainy days in any given month and the amount of stem rust in a given season.

In addition to the more detailed study of the possible correlation between temperature and rainfall on the one hand and stem rust infection on the other, it was deemed advisable to determine the effect of the mean temperature and total precipitation of the last two months of the growing season on the development of stem rust throughout the experimental territory during the whole five-year period. To obviate complications, incident to differences in varietal susceptibility, time of maturity, and pathogenicity of physiologic forms, three varieties of hard red spring wheat (Haynes, Power, and Preston) were chosen because of their similar growth period and uniform rust susceptibility; also, only such nurseries and experimental years were taken into consideration from and in which physiologic forms were isolated that under normal conditions attacked very heavily the three varieties in question.

The various uniform rust nurseries are listed in tables 50 to 52, according to the time of maturing of the three wheat varieties. In each of these tables are recorded the percentages of rust on each variety, each year, at each locality. Also the average infection for the three varieties is given. The corresponding monthly and bi-monthly mean temperatures and total precipitations also are included. From these data, the correlations between 264 varietal units and the climatic conditions in 89 nursery years were determined by the accepted methods.[9]

[9] Grateful acknowledgment is made to Dr. H. K. Hayes, Professor of Plant Breeding, University of Minnesota, and to Dr. O. K. Tedin, formerly of the Institute of Genetics, University of Lund, Sweden, recently Fellow, International Education Board, and situated at the University of Minnesota, for their kind assistance in computing the data.

TABLE 50.—*Estimated stem rust infection on three varieties of hard red spring wheat of similar susceptibility and maturity, and prevailing climatic conditions during May and June, at several experiment stations in the Central West and South West, during the five-year period, 1919–1923, inclusive*

Years and stations	Rust infection				Climatological data					
					Mean temperature (° F.)			Total precipitation (in.)		
	Haynes C.I. 2874	Power C.I. 3697	Preston C.I. 3081	Ave.	May	June	Ave.	May	June	Sum
1919										
Ames, Iowa	75	65	65	68.3	57.4	72.0	64.7	2.34	2.88	5.22
Lincoln, Nebr. ..	100	90	90	93.3	60.7	73.0	66.8	3.83	4.99	8.82
Manhattan, Kans.	90	80	90	86.7	62.8	73.7	68.3	3.13	4.91	8.04
Amarillo, Tex. ..	65	55	70	63.3	61.8	68.9	65.4	2.08	2.94	5.02
Akron, Colo.	35	15	25	25.0	55.7	65.4	60.6	1.59	2.21	3.80
1920										
Lincoln, Nebr. ..	33	25	33	30.3	61.0	73.0	67.0	3.77	2.05	5.82
Akron, Colo.	65	60	65	63.3	...	64.1	60.0[a]	...	4.89	7.69[a]
1921										
Madison, Wis. ..	90	70	80	80.0	60.4	72.2	66.3	5.13	3.52	8.65
Ames, Iowa	40	30	35	35.0	63.7	74.6	69.2	2.81	4.41	7.22
Akron, Colo.	0	0	0	0.0	56.6	67.6	62.1	0.50	1.06	1.56
1922										
Coon Creek, Minn.	25	..	40	32.5	63.2	69.4	66.3	1.99	2.74	4.73
Waseca, Minn. ..	95	95	75	88.3	62.6	70.4	66.5	3.46	2.00	5.46
Madison, Wis. ..	45	20	20	28.3	63.6	68.6	66.1	4.16	3.17	7.33
Ames, Iowa	35	30	45	36.7	63.0	72.8	67.9	8.36	0.87	9.23
Lincoln, Nebr. ..	60	40	25	41.7	64.0	75.8	69.9	2.73	2.95	5.68
Akron, Colo.	2	5	15	7.3	56.5	68.4	62.5	3.69	1.43	5.12
1923										
Coon Creek, Minn.	25	25	25	25.0	59.6	71.2	65.4	3.95	6.13	10.08
Waseca, Minn. ..	35	45	50	43.3	58.6	70.1	64.4	1.52	6.15	7.67
Madison, Wis. ..	40	50	70	53.3	57.0	71.2	64.1	1.90	3.05	4.95
Ames, Iowa	75	75	75	75.0	59.8	71.0	65.4	2.49	5.29	7.78
Lincoln, Nebr. ..	12	15	10	12.3	60.4	71.8	66.1	2.54	5.76	8.30[a]
Akron, Colo.	40	45	50	45.0	54.4	...	60.2[a]	4.94	...	7.54[a]

[a] Normal for missing months included in estimated average.

There seems to be a definite correlation between the mean temperature of the last two months of the growing season and the severity of stem rust infection on susceptible varieties of wheat. Likewise, the total rainfall for these two months can be positively correlated with the intensity of the rust epidemics. However, the correlation coefficients in either case are rather low, $+0.283 \pm 0.038$ and $+0.336 \pm 0.037$, respectively; and the reductions in variability, 4.09 per cent and 5.81 per cent, respectively, are correspondingly small (Tables 53 and 54). There appears to be a rather insignificant positive correlation between the mean temperature and total precipitation of the period in question, namely $+0.074 \pm 0.071$ (Table 55). This probably accounts for the slight reduction in the coefficients of the partial correlations of the amount of rust and mean temperature, with

TABLE 51.—*Estimated stem rust infection on three varieties of hard red spring wheat of similar susceptibility and maturity, and prevailing climatic conditions during June and July at several experiment stations in Minnesota, North Dakota, and South Dakota during the five-year period, 1919–1923, inclusive*

Years and stations	Rust infection				Climatological data					
					Mean temperature (° F.)			Total precipitation (in.)		
	Haynes C.I. 2874	Power C.I. 3697	Preston C.I. 3081	Ave.	June	July	Ave.	June	July	Sum
1919										
St. Paul, Minn. .	50	60	80	66.7	69.1	72.7	70.9	4.75	6.15	10.90
Fargo, N. Dak. .	100	100	100	100.0	69.0	71.9	70.5	2.50	5.56	8.06
Mandan, N. Dak.	40	37	43	40.0	69.0	74.2	71.6	1.17	0.85	2.02
Dickinson, N. Dak.	0	0	0	0.0	69.9	73.8	71.9	0.52	0.53	1.05
Brookings, S. Dak.	100	100	95	98.3	68.6	73.6	71.1	9.30	5.60	14.90
Highmore, S. Dak.	100	95	90	95.0	68.6	74.7	71.7	1.90	2.65	4.55
Newell, S. Dak. .	40	40	40	40.0	70.3	78.0	74.2	0.18	2.90	3.08
1920										
St. Paul, Minn. .	100	100	100	100.0	68.0	70.2	69.1	9.64	1.35	10.99
Fargo, N. Dak. .	100	100	100	100.0	64.8	68.9	66.9	5.89	2.92	8.81
Mandan, N. Dak.	80	65	75	73.3	65.4	71.4	68.4	1.63	2.68	4.31
Dickinson, N. Dak.	22	17	20	20.0	61.6	67.3	64.4	4.32	2.76	7.08
1921										
St. Paul, Minn. .	50	55	45	50.0	73.5	76.7	75.1	3.19	4.27	7.46
Crookston, Minn.	85	85	90	86.7	69.8	73.6	71.7	2.69	3.02	5.71
Morris, Minn. ..	75	15	40	43.3	70.0	74.1	72.1	2.83	3.58	6.41
Fargo, N. Dak. .	95	100	95	93.3	70.4	72.8	71.6	1.40	3.08	4.48
Langdon, N. Dak.	25	25	25	25.0	64.5	68.0	66.3	2.55	4.19	6.74
Edgeley, N. Dak.	70	75	75	73.3	68.0	72.7	70.4	5.76	2.61	8.37
Mandan, N. Dak.	10	6	8	8.0	70.8	74.6	72.7	1.35	3.38	4.73
Dickinson, N. Dak.	12	5	3	6.7	69.2	71.0	70.1	3.09	1.61	4.70
Brookings, S. Dak.	55	55	40	50.0	71.4	74.0	72.7	0.85	3.44	4.29
1922										
St. Paul, Minn. .	80	85	85	83.3	68.3	68.8	68.6	6.76	1.73	8.49
Crookston, Minn.	90	90	90	90.0	66.6	68.1	67.4	1.77	3.45	5.22
Morris, Minn. ..	60	50	75	61.7	68.0	68.4	68.2	0.99	3.17	4.16
Fargo, N. Dak. .	100	98	95	97.7	65.6	67.3	66.5	2.93	1.65	4.58
Langdon, N. Dak.	50	45	65	53.3	61.6	63.3	62.5	4.12	2.96	7.08
Edgeley, N. Dak.	35	40	25	33.3	65.5	66.2	65.9	2.44	1.34	3.78
Mandan, N. Dak.	75	75	70	73.3	66.0	66.6	66.3	3.43	3.17	6.60
Dickinson, N. Dak.	75	80	80	78.3	63.3	64.4	63.9	6.57	1.92	8.49
Brookings, S. Dak.	95	75	90	86.7	69.5	68.3	68.9	3.75	2.81	6.56
Redfield, S. Dak.	80	80	55	71.7	70.1	70.7	70.4	2.67	0.80	3.47
1923										
St. Paul, Minn. .	25	35	45	35.0	70.0	75.2	72.6	4.95	2.90	7.85
Crookston, Minn.	70	60	60	63.3	69.7	72.4	71.1	3.34	4.77	8.11
Morris, Minn. ..	95	95	95	95.0	69.4	74.1	71.8	3.50	3.42	6.92
Fargo, N. Dak. .	75	80	80	78.3	68.1	72.5	70.3	6.73	2.34	9.07
Langdon, N. Dak.	90	90	98	92.7	65.4	70.2	67.6	1.98	0.70	2.68
Edgeley, N. Dak.	90	85	85	86.7	65.5	71.4	68.5	6.43	3.10	9.53
Mandan, N. Dak.	40	50	55	48.3	67.2	73.4	70.3	1.94	4.12	6.06
Dickinson, N. Dak.	75	75	75	75.0	65.3	70.0	67.7	4.49	4.67	9.16
Brookings, S. Dak.	70	70	75	71.7	68.8	74.1	71.5	5.74	1.94	7.68
Redfield, S. Dak.	55	55	60	56.7	69.4	75.0	72.2	5.33	2.13	7.46

TABLE 52.—*Estimated stem rust infection on three varieties of hard red spring wheat of similar susceptibility and maturity, and prevailing climatic conditions during July and August, at several experiment stations in the Northern and Western United States and in Western Canada, during the five-year period, 1919–1923, inclusive*

Years and stations	Rust infection				Climatological data					
					Mean temperature (° F.)			Total precipitation (in.)		
	Haynes C.I. 2874	Power C.I. 3697	Preston C.I. 3081	Ave.	July	Aug.	Ave.	July	Aug.	Sum
1919										
Archer, Wyo. ...	65	65	65	65.0	69.6	68.4	69.0	2.75	1.20	3.95
1920										
Archer, Wyo. ...	50	50	50	50.0	65.8	63.4	64.6	1.25	1.27	2.52
Morden, Man. ...	50	50	65	55.0	69.0	69.0	69.0	1.74	0.59	2.33
Winnipeg, Man. .	65	50	75	63.3	66.0	70.0	68.0	0.76	1.70	2.46
Brandon, Man. ..	65	50	65	60.0	65.0	67.0	66.0	2.15	4.34	6.49
Indian Head, Sask.	55	65	65	61.7	65.0	64.0	64.5	5.24	1.42	6.66
Saskatoon, Sask. .	40	40	35	38.3	67.0	64.0	65.5	2.24	2.72	4.96
Rosthern, Sask. .	75	40	35	50.0	66.0	65.0	65.5	2.53	1.67	4.20
Scott, Sask.	15	8	20	14.3	64.0	64.0	64.0	3.74	2.37	6.11
Edmonton, Alta. .	25	15	25	21.7	65.0	59.0	62.0	2.33	1.97	4.30
1921										
Duluth, Minn. ..	50	..	55	52.5	70.8	63.6	67.2	5.41	2.84	8.25
Morden, Man. ...	80	75	80	78.3	70.0	64.0	67.0	6.60	3.40	10.00
Winnipeg, Man. .	60	70	85	71.7	70.0	64.0	67.0	3.71	2.46	6.17
Brandon, Man. ..	50	40	40	43.3	69.0	64.0	66.5	0.61	2.60	3.21
Indian Head, Sask.	80	10	35	41.7	65.0	61.0	63.0	3.78	1.13	4.91
Saskatoon, Sask. .	5	30	50	28.3	66.0	58.0	62.0	3.04	0.31	3.35
Rosthern, Sask. .	80	80	75	78.3	65.0	61.0	63.0	4.91	0.64	5.55
Scott, Sask.	0	T	T	T	63.0	60.0	61.5	1.65	0.56	2.21
Vermilion, Alta. .	0	0	0	0.0	61.0	57.0	59.0	4.26	2.97	7.23
Edmonton, Alta. .	0	0	0	0.0	61.0	57.0	59.0	3.65	1.56	5.21
Lacombe, Alta. ..	0	0	0	0.0	61.0	58.0	59.5	3.28	0.98	4.26
1922										
Chatham, Mich. .	15	25	20	20.0	62.8	63.6	63.2	5.14	1.22	6.36
Duluth, Minn. ...	68	..	60	64.0	63.6	64.2	63.9	2.30	2.01	4.31
Archer, Wyo. ...	0	T	T	T	65.5	69.0	67.3	1.81	2.35	4.16
1923										
Chatham, Mich. .	30	20	40	30.0	64.2	58.0	61.1	5.86	2.75	8.61
Duluth, Minn. ...	65	90	60	71.7	64.6	60.3	62.5	5.40	1.76	7.16
Archer, Wyo. ...	35	50	50	45.0	67.5	63.7	65.6	1.62	2.92	4.54

rainfall constant, on the one hand, and the severity of infection and total precipitation with temperature constant, on the other, as compared with those of the independent correlations (See table 56).

Figure 37 illustrates the combined effect of mean temperature and total precipitation on the development of stem rust. Here the average infection on the three susceptible wheat varieties was correlated with the weather conditions in the 89 nursery years. No infection whatever occurred where the total rainfall was below 2 inches or where the temperature was less

TABLE 53.—*Correlation between stem rust infection on three susceptible varieties of hard red spring wheat and the mean temperature during the last two months of wheat growth. Mean temperature, subject; rust infection, relative. Coefficient of correlation = + 0.283 ± 0.038; control of variability = 4.09 per cent*

TEMPERATURE (FAHRENHEIT)	RUST INFECTION 0%	20%	40%	60%	80%	100%	
60°	9	3	5	4			21
63°	10	13	6	9	8	1	47
66°	3	14	14	19	17	15	82
69°	2	2	8	15	22	11	60
72°	5	3	7	9	8	16	48
75°			4	2			6
	29	35	44	58	55	43	264

TABLE 54.—*Correlation between stem rust infection on three susceptible varieties of hard red spring wheat and the total precipitation during the last two months of wheat growth. Total precipitation, subject; rust infection, relative. Coefficient of correlation = + 0.336 ± 0.037; control of variability = 5.81 per cent*

PRECIPITATION (INCHES)	RUST INFECTION 0%	20%	40%	60%	80%	100%	
0″	3						3
3″	13	6	15	21	7	6	68
6″	13	21	18	26	17	18	113
9″		8	11	9	30	13	71
12″				2	1	3	6
15″						3	3
	29	35	44	58	55	43	264

than 60° F. Barring one exception, not more than about 40 per cent rust appeared at or below 62° F. Ninety to one-hundred per cent stem rust was found only at the mean temperature range of 66 to 72° F., coupled with a total rainfall exceeding 2.5 inches. The multiple correlation between these two weather conditions and the severity of the stem rust infection was + 0.4239, indicating a reduction of variability of 9.43 per cent (Table 56). These results would justify the conclusion that in the final analysis weather conditions of the last two months of the growing season play only a minor, even if very important, part in the intenseness of stem rust epidemics, for it is held by statisticians that, if all essential factors have been considered, the multiple correlation coefficient should be 0.9, or above.

Sunshine, as indicated by the number of clear days per month, seems to be of no value in so far as determining its effect on the severity of infection goes. All other conditions being favorable, the normal light intensity during the growing season seems to be quite sufficient for the best development of the rust fungus. A proper amount of dew at the critical time after all may be the decisive factor in infection. This is a matter that deserves due consideration and careful study. The possibility that undetected virulent physiologic forms are responsible for the intensity of an infection is certainly not exhausted.

Aecial Host

Last but not least the rôle the common barberry is likely to play in the severity of a rust epidemic must be given serious consideration. Bringing

TABLE 55.—*Correlation between mean temperature and total precipitation during the last two months of wheat development in eighty-nine nursery years. Mean temperature, subject; total precipitation, relative. Coefficient of correlation = + 0.074 ± 0.071; control of variability = 0.28 per cent*

TEMPERATURE (FAHRENHEIT)	PRECIPITATION (INCHES) 0″	3″	6″	9″	12″	15″	
60°		2	2	3			7
63°		5	9	2			16
66°		5	15	8	1		29
69°		7	5	6	2		20
72°	1	2	7	3	1	1	15
75°		1	1				2
	1	22	39	22	4	1	89

TABLE 56.—*Correlation coefficients and regression values for stem rust infection on three varieties of hard red spring wheat, equally susceptible to stem rust and maturing at about the same time, and the mean temperature and total precipitation during the last two months of wheat development*

Series of variables		Coefficients of correlation	Regression values
Symbols[a]	Combinations		
	Correlations		
r12	Rust infection and mean temperature.....	+0.2828	.....
r13	Rust infection and total precipitation.....	+0.3357	.....
r23	Mean temperature and total precipitation....	+0.0740	.....
	Regression values		
	Total precipitation, constant		
b12.3	Rust infection and mean temperature.....	.....	+0.2594
b21.3	Mean temperature and rust infection.....	.....	+0.2907
	Mean temperature, constant		
b13.2	Rust infection and total precipitation.....	.....	+0.3165
b31.2	Total precipitation and rust infection.....	.....	+0.3422
	Partial correlations		
	Total precipitation, constant		
r12.3	Rust infection and mean temperature.....	+0.2746	.....
	Mean temperature, constant		
r13.2	Rust infection and total precipitation.....	+0.3291	.....
	Multiple correlation		
R1.23	Combined effect of mean temperature and total precipitation on stem rust infection..	+0.4239	.....

[a] r = correlation coefficient; b = regression value; R = coefficient of multiple correlation; 1 = rust infection; 2 = mean temperature; 3 = total precipitation.

up the Fargo question again, we note that according to the findings of Melhus, Durrell and Kirby (18) the weather conditions in May of 1922 and 1919 were extremely favorable for the germination of teliospores and sporidia. We find furthermore that the weather was particularly favorable in June of 1922, and somewhat less so in June, 1919, for the development of the greatest amount of infection on barberry.[10] The weather conditions of the other years were not quite so favorable.

The records of Mr. G. C. Mayoue, State Leader of barberry eradication in North Dakota, show that in 1919 there were found some 43 infected barberry bushes near and around Fargo. Altogether 162 barberry bushes were removed in Cass County that year. In 1920, 20 barberry bushes were discovered in the county and removed. In 1921 nine bushes were destroyed; a resurvey in that year revealed 139 sprouts, a goodly number of which were infected. In 1922, 93 bushes were found in the original survey, and 717 sprouts in a resurvey; most of these were badly rusted. All were destroyed. Still, in 1923 again 86 bushes were found and finally destroyed.

[10] From unpublished data of Mr. L. W. Melander's thesis for the degree of Master of Science, submitted to the University of Minnesota in 1924.

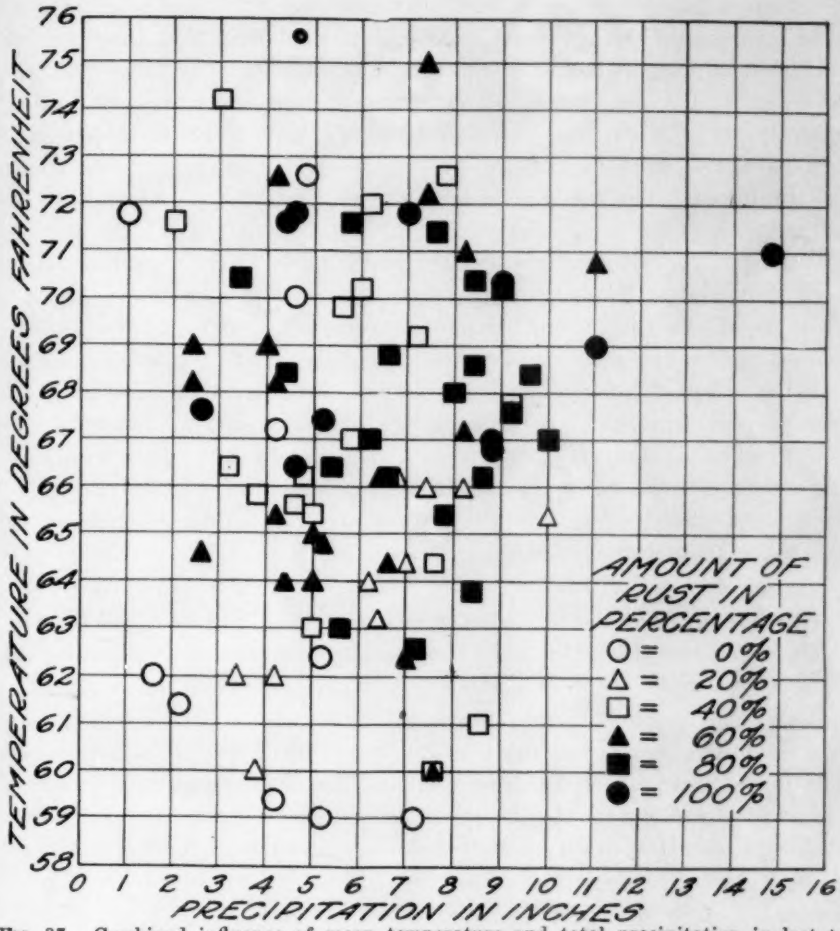


FIG. 37. Combined influence of mean temperature and total precipitation in last two months of wheat development on severity of stem rust infection, during the five years, 1919–1923, inclusive.

According to Christensen,[11] a bush of average size, about 6 to 7 feet high, has about 35,000 leaves. From actual counts approximately 80 per cent of the leaves were infected with rust, making a total of about 28,000 infected leaves on an average-sized barberry. Eight hundred leaves were selected at random, and on them there were 6,720 aecial clusters, averaging

[11] From unpublished results obtained by Dr. J. J. Christensen, Assistant Plant Pathologist, Agricultural Experiment Station, University of Minnesota, and Agent, Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, in 1922, on barberries in Rice County, Minnesota.

8 + clusters for each infected leaf. As many as 222 aecial clusters were found on a single leaf. Counts on 350 clusters showed that there was an average of 36 cups per cluster, the actual number varying from 1 to 290. The number of spores in a single cup ranged from 8,000 to 15,000. Consequently, on the average infected barberry leaf there were produced 2,304,000 aeciospores, and on the average-sized bush 64,512,000,000 spores were produced. The last figure is about 40 times the population of the world.

It is not inconceivable then that the particularly heavy stem rust attack which prevailed at Fargo, N. Dak., from 1919 to 1923, inclusive, and the lack there of a consistent correlation between the severity of infection and the existing weather conditions, were due chiefly to the persistent presence in that vicinity of infected barberry bushes. The weather conditions did favor the development of the rust on the barberry, and an immeasurable quantity of aecial material was produced each year, so that there was really little chance for the susceptible varieties to escape heavy infection, unless the climatic conditions were totally unfavorable for the development of the rust on the grain, which was not the case.

Stability of Physiologic Forms under Diverse Cultural Conditions

There can be very little doubt but that the varieties of *P. graminis* are relatively fixed in their parasitism. It is evident from the exhaustive studies of Stakman and his coworkers (35, 34, 36, 27) and others, that these varieties do not change readily, if at all, genetically; that they do not seem easily to lose their inherent parasitic capabilities or gain increased virulence as a result of biotic, climatic, chemical, or physical influences. But do the physiologic forms of *tritici* variety behave in similar manner?

Uniformity of Behavior Over Long Periods of Time

A summary of the results regarding the action of several forms of *P. graminis tritici* cultured on the various differential varieties of *Triticum spp.* under a wide range of environmental conditions and over a long period of time is given in tables 57 and 58. Form 1 had been grown in the greenhouse as a stock culture for over eight years, covering nearly 150 urediniospore generations. A monosporous culture of this form was started in February, 1924, and since then has been grown in a spore-proof cage for 10 generations. Form 9 was grown as a multisporous culture in the greenhouse for approximately five years (over 100 urediniospore generations), and as a single-spore culture since March 1, 1924, (10 generations) in a spore-proof cage. Forms 29 and 38 have been cultured as stock strains only for about two, and one and one-half years, respectively, or for some 50-odd generations each.

TABLE 57.—*Constancy of behavior of multisporous cultures of physiologic forms of Puccinia graminis tritici grown in the greenhouse for many consecutive uredinospore generations*

Experimental conditions	Reaction of differential varieties											
	Little Club C. I. 4066	Marquis C. I. 3641	Kanred C. I. 5146	Kota C. I. 5878	Arnautka C. I. 1493	Mindum C. I. 5296	Arnautka C. I. 6236	Kubanka C. I. 2094	Acme C. I. 5284	Einkorn C. I. 2433	Vernal C. I. 3686	Khapli C. I. 4013
P. graminis tritici form 1												
(Material collected Sept. 12, 1915; form identified Nov. 11, 1915; experiment concluded May 30, 1924)												
Number of trials	72	34	45	15	21	21	12	18	8	11	10	4
Plants inoculated	1127	336	439	121	186	181	109	154	74	93	86	30
Plants infected	1044	314	42	116	115	142	93	140	74	88	76	23
Minimum infection	3+	3	0	3–	0;	0.	0;	3–a	3–	3–	0.	0;
Maximum infection	4++	4++	0;	4–	1	1+	1+	4	4–	3+	1+	1++
P. graminis tritici form 9												
(Material collected July 27, 1918; form identified Feb. 22, 1919; experiment concluded May 30, 1924)												
Number of trials	63	22	30	18	19	25	13	30	11	10	32	11
Plants inoculated	880	188	257	177	161	199	116	276	110	100	353	89
Plants infected	771	145	24	155	151	170	111	218	109	99	295	74
Minimum infection	3	3=	0	3=	3–a	3a	3a	3a	3–	3	3=	0.
Maximum infection	4+	4+	0;	4+	4+	4+	4+	4+	4a	4	4+	1

TABLE 57.—(*Continued*)

Experimental conditions	Reaction of differential varieties											
	Little Club C. I. 4066	Marquis C. I. 3641	Kanred C. I. 5146	Kota C. I. 5878	Arnautka C. I. 1493	Mindum C. I. 5296	Arnautka C. I. 6236	Kubanka C. I. 2094	Acme C. I. 5284	Einkorn C. I. 2433	Vernal C. I. 3686	Khapli C. I. 4013
P. graminis tritici form 29 (Material collected June 23, 1922; form identified Oct. 20, 1922; experiment concluded Nov. 3, 1924)												
Number of trials	23	5	7	4	16	23	16	18	10	4	4	3
Plants inoculated	214	44	76	40	160	210	141	184	88	48	50	30
Plants infected	173	37	6	34	153	182	122	162	74	45	33	29
Minimum infection	4–	3+	0	3	0;	0;	0;	X=	X	3+	0	0;
Maximum infection	4++	4+	0.	4	4	4	4+	X++	4	4+	0;	1=
P. graminis tritici form 38 (Material collected Aug. 10, 1922; form identified Mar. 8, 1923; experiment concluded Nov. 3, 1924)												
Number of trials	26	27	14	17	11	16	12	12	6	5	3	3
Plants inoculated	308	256	130	161	104	137	135	91	69	54	33	33
Plants infected	261	232	103	127	99	128	127	85	67	49	31	31
Minimum infection	4=	0;	3+	3=[c]	0;	0;	X	X=	X+	3	0;	0;
Maximum infection	4++	2++	4++	3++	4+	4–	4+	4+	3++	4=	1–	1

[c] = infected areas frequently chlorotic, apparently on account of unfavorable climatic conditions;
[a] = normal uredinia often accompanied by a necrotic effect; infection somewhat similar to, but not identical with, "X" type; phenomenon evidently of genetic nature.

TABLE 58.—*Correlation between the behavior of monosporous cultures of physiologic forms of Puccinia graminis tritici,*

TABLE 58.—*Correlation between the behavior of monosporous cultures of physiologic forms of Puccinia graminis tritici, grown in spore-proof cages, and that of multisporous (stock) cultures of the same forms, grown in open greenhouse compartments*

Type of culture	Experimental conditions	Reaction of differential varieties											
		Little Club C. I. 4066	Marquis C. I. 3641	Kanred C. I. 5146	Kota C. I. 5878	Arnautka C. I. 1493	Mindum C. I. 5296	Arnautka C. I. 6236	Kubanka C. I. 2094	Acme C. I. 5284	Einkorn C. I. 2433	Vernal C. I. 3686	Khapli C. I. 4013
	P. graminis tritici form 1 (Experiment commenced March 12, 1924; concluded Nov. 21, 1924)												
MONOSPOROUS	Number of trials	12	3	4	2	2	2	2	4	2	3	3	3
	Plants inoculated ...	169	37	55	22	27	34	18	28	23	39	45	48
	Plants infected	153	37	6	21	21	33	17	25	23	35	35	43
	Minimum infection ..	4	4–	0	4–	0;	0;	0;	3	4=	4=	0;	0;
	Maximum infection ..	4++	4+	0.	4+	0;	0;	0;	4+	4++	4–	1+	1=
STOCK	Minimum infection ..	3+	3	0	3–	0;	0.	0;	3=[a]	3–	3–	0.	0;
	Maximum infection ..	4++	4++	0;	4–	1	1+	1+	4	4–	3+	1+	1++
	P. graminis tritici form 9 (Experiment commenced March 8, 1924; concluded Nov. 21, 1924)												
MONOSPOROUS	Number of trials	10	2	2	2	3	6	6	4	4	2	4	2
	Plants inoculated ...	129	25	21	25	34	63	65	35	40	28	53	30
	Plants infected	125	18	1	25	33	59	65	33	40	24	53	17
	Minimum infection ..	4–	4–	0	3+[a]	4=	3–[a]	3+	3=[a]	3=	3++	3++	0;
	Maximum infection ..	4+	4+	0	4	4+	4+	4+	4+	4	4–	4++	1–
STOCK	Minimum infection ..	3	3=	0	3=	3=[a]	3[a]	3[a]	3[a]	3–	3	3=	0.
	Maximum infection ..	4+	4+	0;	4+	4+	4+	4+	4+	4[a]	4	4+	1

It will be seen from table 57 that there is a certain fluctuation in the type and degree of infection of each physiologic form on every one of the differential hosts. This fluctuation, however, is maintained within certain bounds regardless of the variation in environmental and cultural conditions. Stakman and Levine (30) have found that when a given host plant is resistant to a given form the infection range may extend from 0 to 2 ++; when a variety is susceptible, the infection may be from 3 = to 4 ++; when the reaction of a differential host is indeterminate, the infection is heterogeneous in nature and may fluctuate from x = to x ++ or even from 0 to 4 ++, depending on the prevailing conditions. As a result of subsequent work, it has been found that it probably would be better to designate those varieties on which the reaction ranges from 3 = to 3 + as "moderately resistant" rather than as "susceptible." While there is no hypersensitiveness on such varieties, still the rust develops so poorly that the plant for practical purposes is at least moderately resistant. These authors found that all of the 37 forms of *P. graminis tritici* they described behave in like manner. Peltier's (23) intensive studies with two of the forms supplied him by the Minnesota laboratory fully substantiated the above results.

Monosporous cultures produced infection types quite similar to those produced by the stock cultures from which they were isolated, always falling fairly within the established range limits (See table 58). Multisporous cultures of form 9 often produce an infection on the durum varieties which approximates the "x" type. The monosporous cultures of this form act in like manner notwithstanding the additional protection against accidental contamination by means of "solitary confinement" in specially constructed spore-proof cages.

Consistency in Behavior of Different Strains of Identical Forms

Even though there may be some differences in the morphology of the urediniospores of individual strains of an identical physiologic form of *P. graminis tritici,* there is no very apparent dissimilarity in their action on the differential varieties of wheat. Forms 17 and 21 were selected to illustrate this point because of their wide distribution and frequent occurrence. Tables 59 and 60 show that there is some fluctuation in the action of the several strains of a given form on the various differential hosts but always within the range of infection of a single form when tested for many urediniospore generations under varying environmental conditions. Repeated cross inoculations from congenial to resistant differential hosts and *vice versa* did not affect in any way the pathogenicity of the physiologic forms in question.

It would appear, therefore, that the extensive and intensive investigations of this subject warrant the conclusion at the present time that para-

sitically and morphologically the different physiologic forms of *P. graminis tritici* are but little and only temporarily influenced by external conditions. Consequently it does not seem as though these forms could originate through a process of adaptation. As has been suggested by Stakman, Levine, and Leach (33), they very likely come into existence either through mutation or by hybridization.

There is as yet no definite experimental evidence that the physiologic forms of the stem rust pathogene arise as mutations. Further careful investigations along this line are now in progress. In 1918, Stakman Piemeisel, and Levine (36, p. 228) reported that upon inoculating *Berberis vulgaris* L. with teliospores from *Agrostis stolonifera* L. they obtained successful and normal infection on wheat, oats, and rye. The only physiologic form known to parasitize normally *Agrostis stolonifera* is *P. graminis agrostis*, whereas, wheat, oats, and rye can be attacked properly only by *P. graminis tritici*, *P. graminis avenae*, and *P. graminis secalis*, respectively. The percentage of infected plants was rather low, but this is generally the case when inoculations are made with aeciospores. Three different rust varieties then developed on the barberry from the one sown. The authors do not attempt to explain the results. They do suggest accidental contamination, although all possible precautions had been taken to prevent this. It is not impossible, therefore, that we are dealing here with a genuine case of segregation and recombination of genetic characters of a heterozygous rust in the aecial stage during the process of nuclear division and fusion. The general question of the origin of physiologic forms of *P. graminis tritici*, and their genetic nature in particular, are now being studied intensively.

GENERAL DISCUSSION

It may be seen from the results presented in this paper that almost all of the common wheat varieties grown in the uniform rust nurseries during the five-year period, 1919–1923, inclusive, were highly susceptible to black stem rust in the field. The durum varieties, as a class, were on the average much more resistant; the emmers were practically immune; Little Club was completely susceptible throughout. At least traces of stem rust were observed in all nurseries except those at Edmonton and Lacombe, Alta., in 1921. At Dickinson, N. Dak., in 1919, and at Akron, Colo., Scott, Sask., and Vermilion, Alta., in 1921, the maximum rust infection on any variety was recorded as a trace. But the fact that percentage estimates were obtained in 89 of the 95 experiments, or nursery years, is ample evidence of the prevalence of stem rust and the necessity for rust investigations in the wheat-growing regions.

Some of the physiologic forms isolated from the different nurseries were extremely virulent, while others were rather innocuous. In general, the

TABLE 59.—*Agreement in behavior of separate cultures of Puccinia graminis tritici, form 17, collected in different years at different places*

Cultures			Reaction of differential hosts										
Year collected	Place of collection	Acc. no.	Little Club C. I. 4066	Marquis C. I. 3641	Kanred C. I. 5146	Kota C. I. 5878	Arnautka C. I. 1493	Mindum C. I. 5296	Arnautka C. I. 6236	Kubanka C. I. 2094	Acme C. I. 5284	Einkorn C. I. 2433	Vernal C. I. 3686	Khapli C. I. 4013
1919	Akron, Colo.	251	4	4++	0;	3	3	3	3	4=	3	3	0;	0
do	Mandan, N. Dak.	202	4	4	0	4–	4	4=	4=	3+	3++	3	0;	0
1920	Indian Head, Sask.	513	4	4	0	3	4	4	4	4	3++	3+	1	1
do	Mandan, N. Dak.	467	4	3	0	3–	3++	3++	4=	4–	3++	3	1=	1=
do	Rosthern, Sask.	532	4+	4	0	3±	4	4	4	3±	4	4	0;	1
do	Saskatoon, Sask.	518	4	4	0	3	4	–	3+	3	–	3+	1	–
do	Winnipeg, Man.	512	4	4	0	3	3	4–	4	3	3+	3	1	–
1921	Brookings, S. Dak.	589	4+	4–	0;	4	4	4+	4	4+	3++	3	0;	1=
do	St. Paul, Minn.	592	4–	4	0	3	4–	4	4	4=	3±	3	0;	1
do	Edmonton, Alta.	650	4	4	0	3	4	4	4	4	4	3+	0;	1
do	Winnipeg, Man.	613	4+	4	0	3+	4+	4	4	4	3	3+	0;	0;
1922	Ames, Iowa	767	4	4=	0	4	3+	4–	4	4+	3+	3	0.	1
do	Coon Creek, Minn.	773	4–	3++	0	3++	3++	4=	3±	4–	4–	4	0;	1–
do	Duluth, Minn.	807	4	4=	0	3++	3++	4	4	4–	3+	4=	0;	1+
do	Fargo, N. Dak.	789	4+	4	0	3++	4–	4	4	4–	3++	3+	0;	1=
do	Morris, Minn.	784	4	4	0	3++	4	4=	4–	3++	3+	3+	0;	1=
do	Redfield, S. Dak.	777	3++	4	0	3+	4	4+	4–	3++	3+	3+	0;	1=
1923	Mandan, N. Dak.	930	4=	4–	0	3	4	4	4	4–	3	3+	0;	1=
Range of infection for—														
Eighteen collections of f. 17														
Minimum infection			3++	3	0	3–	3	3	3–	3–	3–	3	0.	0
Maximum infection			4+	4++	0;	4	4+	4+	4	4+	4	4	1	1+
Prototype culture of f. 17														
Minimum infection			3	3	0	3–	4	3	3	3	3	3	0.	0.
Maximum infection			4++	4+	0;	3+	4++	4++	4	4	4–	3+	1	0;

TABLE 60.—*Agreement in behavior of separate cultures of Puccinia graminis tritici, form 21, collected in different years at different places*

Cultures			Reaction of differential varieties											
Year collected	Place of collection	Acc. no.	Little Club C. I. 4066	Marquis C. I. 3641	Kanred C. I. 5146	Kota C. I. 5878	Arnautka C. I. 1493	Mindum C. I. 5296	Arnautka C. I. 6236	Kubanka C. I. 2094	Acme C. I. 5284	Einkorn C. I. 2433	Vernal C. I. 3686	Khapli C. I. 4013
1921	Duluth, Minn.	615	4	4+	0	3++	4+	4++	4+	3+	4=	0;	0;	1=
do	Fargo, N. Dak.	582	4+	3++	0	3++	3++	4	4	4–	3+	1–	0;	1=
do	Langdon, N. Dak.	585	4+	4+	0	4=	4+	4	4++	4±	3++	1	0;	1
1922	Akron, Colo.	770	4	4–	0	4=	4	4–	4–	4	3	0;	0;	1=
do	Brookings, S. Dak.	775	4+	4	0	3++	4=	4	3++	4–	3+	0;	0;	1=
do	Chatham, Mich.	803	4	4–	0	3+	4–	4–	4	4–	3++	0;	0;	1–
do	Coon Creek, Minn.	774	4	4	0	3++	4=	4–	4–	4	3±	0;	0;	1–
do	Crookston, Minn.	790	4–	4–	0	4=	4–	4=	4=	3++	3	0;	0;	0;
do	Edgeley, N. Dak.	781	3–	4–	0	3±	4=	4–	4=	4=	4=	0.	1–	1=
do	Lincoln, Nebr.	769	4	4	0	3+	4=	4	4–	4	3±	0.	0;	1–
do	Madison, Wis.	766	4	4–	0	4	4	4	4	4=	4	0;	0	1
do	Redfield, S. Dak.	778	4+	4+	0	4=	4–	4	3+	4	3–	1+	0;	0;
do	Waseca, Minn.	772	4	4	0;	4=	4–	4	4–	4–	3++	0;	0;	0.
1923	Akron, Colo.	909	4	4	0	4	4–	4+	4–	4–	4–	0;	0;	1–
do	Brookings, S. Dak.	918	4	4	0	3+	4–	4+	4+	4	3	0;	1=	0;
do	Coon Creek, Minn.	902	4=	4	0	3+	4	4	4	3++	4	0;	0;	1=
do	Edgeley, N. Dak.	922	4–	4=	0	3++	4	4–	4+	4=	3++	0;	0;	1–
do	Lincoln, Nebr.	898	3++	4+	0.	3+	4	4–	3+	3+	3+	1	0;	1=
do	Morris, Minn.	915	3+	4	0	4	4–	4+	4+	4–	3	0;	0;	0;
Range of infection for—														
Nineteen collections of f. 21														
Minimum infection			3–	3++	0	3–	3++	4=	3+	3+	3–	0.	0	0.
Maximum infection			4+	4+	0;	4	4+	4++	4++	4+	4	1+	1–	1
Prototype culture of f. 21														
Minimum infection			3+	3+	0	3–	3+	3	3–	3–	3+	0.	0	0;
Maximum infection			4+	4+	0;	4	4	4+	4	4=	4	1++	0;	1–

reaction of the varieties in the greenhouse approximated their behavior in the field, whenever the same physiologic forms were concerned. No correlation between the virulence of the various physiologic forms on differential hosts and their prevalence and distribution could be definitely established. Some forms were widely distributed and of common occurrence; others were found infrequently and in restricted areas.

The distribution and prevalence of the different physiologic forms seem to depend on a multiplicity of factors. In the first place, it is quite obvious that resistant varieties of wheat, grown in a given region, undoubtedly impose a definite restraint on the occurrence of certain forms of *P. graminis tritici*. It also is very likely that the difference in climatic conditions in the various parts of the country plays an important part in the distribution of these forms. Finally, the common barberry may not be an insignificant factor, as long as there exists the possibility for stem rust forms to hybridize in the aecial stage.

There is convincing evidence that certain of the physiologic forms of *P. graminis tritici* differ not only parasitically but also morphologically; in anatomical structure as well as in infection capabilities. While the shape and size of spores of a given physiologic form evidently are due partly to true genetic factors, environment, as would be expected, affects their expression profoundly. For this reason physiologic forms can be distinguished best by their action on differential hosts.

The mean temperature and total precipitation of the last two months of the growing season can be definitely correlated with the intensity of stem rust infection on susceptible wheat varieties. However, the multiple correlation between these two weather conditions and the severity of the rust epidemic was only +0.4239, from which it might be deduced that temperature and rainfall, although very important factors, are by no means the sole determiners of a successful stem rust epidemic.

The uneven quantitative distribution of the rust inoculum, the degree of maturity and general condition of the wheat plant at the time infection first takes place, the type of soil and method of fertilization, the right amount of dew fall at the critical moment, prevailing winds and sufficient sunshine, and finally the proximity of infected barberry bushes, all contribute to the extent and intenseness of the rust attack even on innately susceptible sorts.

External conditions affect but slightly and only temporarily either the pathogenicity or the morphology of physiologic forms of *P. graminis tritici*. It is improbable, therefore, that these forms originate through a progressive adaptation to changing environment. It is more likely that they come into existence as a result of occasional mutation or regular hybridization.

From the foregoing discussion it follows that the losses due to the stem rust scourge could be effectively reduced by the use of desirable resistant varieties, by the eradication of the alternate host, by judicious cultural practices, and perchance by the application of certain chemical dusts or sprays.

SUMMARY AND CONCLUSIONS

1. For the purpose of studying the effect of stem rust on different varieties of wheat under field conditions, and in order to determine the occurrence of physiologic forms of *Puccinia graminis tritici* in the spring wheat region, a series of uniform rust nurseries was established and operated at various experiment stations in the United States and Western Canada.

2. The maximum number of varieties of wheat and emmer tested in any one year was 24. The greatest number of stations at which uniform rust nurseries were grown in a single year also was 24. Altogether, during the five years, 1919–1923, inclusive, there were uniform rust nurseries at 34 different experiment stations.

3. The percentage of rust infection was estimated, whenever possible, just before the plants ripened, on the basis of the scale designed for this purpose in the Office of Cereal Crops and Diseases of the United States Department of Agriculture. Rust estimates in percentages were recorded in 89 of the 95 nursery years during which the experiment was in operation.

4. There was a distinct difference in the quantity of rust on different varieties, at different stations, in different years. In general, Acme, Monad, Pentad, and Kota seemed to withstand the stem rust attack in the field; Khapli always was highly resistant, and Vernal practically always so. The other varieties were susceptible in varying degrees.

5. In general, the reaction of the varieties in a given field nursery was the same as it was in the greenhouse to pure cultures of the physiologic forms isolated from the nursery in question. This, however, was not always true of Acme, Monad, Pentad, Kota, and Vernal, which often escaped infection under field conditions.

6. Nearly all of the hard red spring wheat varieties grown were susceptible to the prevailing physiologic forms. Of the durums, some varieties were considerably more susceptible than others, but as a class the durum varieties had a lower percentage of infection than either Marquis or the whole group of common wheats.

7. Rust specimens were collected each year from the different uniform nurseries and their identity was determined by the methods described by Stakman and Levine. Altogether 78 collections were studied; 20 of these consisted of two forms each, and one yielded three forms.

8. Nineteen different physiologic forms of *P. graminis tritici* were isolated from the collections made at the various uniform rust nurseries during the first five years of the experiment.

9. Little Club was completely susceptible to all of the forms isolated, in the greenhouse as well as in the field.

10. All of the forms isolated, except two, attacked all of the hard red spring varieties tested under greenhouse conditions. Marquis was resistant to one of the two excepted forms, and Kota was resistant to the other.

11. In the greenhouse, the durums did not always behave as a group. Some of them were resistant to certain physiologic forms and susceptible to others, and *vice versa*. As a rule, the different durum varieties behaved differently. However, to some forms they were resistant *en masse*, and to others they were all susceptible.

12. Two of the physiologic forms isolated infected Vernal emmer normally under greenhouse conditions. None of the forms could infect Khapli emmer to any appreciable extent under any circumstance.

13. Einkorn was moderately susceptible to most of the forms isolated, but extremely resistant to two of them, *viz.*, forms 21 and 34.

14. Some of the physiologic forms isolated occurred frequently and were widely distributed; others occurred rarely and in limited areas. Physiologic form 17 was isolated from the greatest number of stations, and was to a greater or less extent a factor in the rust epidemics of the spring wheat region in each year between 1919 and 1923, inclusive. Form 21 appeared in almost as many different places as form 17, but was found in the uniform rust nurseries only during the last three years of the present experiment. Forms 5, 22, 34, and a few others, were procured only once each.

15. The frequency of occurrence of the different physiologic forms was not always coextensive with their distribution. In general, neither prevalence nor distribution of a given physiologic form could be directly correlated with the degree of its virulence on the differential varieties of wheat.

16. The prevalence of different forms of *P. graminis tritici* and the extent of their distribution are either inhibited or enhanced, by the climatic conditions prevailing in various parts of the country, by the wheat varieties grown in the different regions, and by the manner in which these forms originate and develop.

17. Eight physiologic forms of the *tritici* variety were chosen for a comparative morphological study. One hundred spores were found to constitute a representative random sample. The size and shape of individual urediniospores were determined and grouped in convenient classes. Monosporous as well as multisporous (stock) cultures were studied.

18. There appeared to be pronounced and significant differences in the size and shape of the urediniospores of some of the forms even when grown under identical conditions. These differences in many instances were considerably greater than the fluctuations induced in an individual form by altering the cultural conditions. They were practically always greater than the differences caused by a diversity in the geographic origin of two strains of a particular form.

19. No definite parallelism could be found between the differences in pathogenicity and the differences in morphology of the physiologic forms studied.

20. Even though there is a real morphologic basis for the distinction of physiologic forms of *P. graminis tritici* when developed under uniform conditions, they are most adequately identified by their parasitic behavior on certain varieties of wheat.

21. The difference between the size and shape of the urediniospores of the different physiologic forms of the *tritici* variety were sometimes as great as the differences in the size and shape of these spores of the composite forms (varieties) of *Puccinia graminis*; that is, different physiologic forms of *P. graminis tritici* often differ from each other morphologically quite as much as the *tritici* variety *per se* differs from the *avenae* or *secalis* varieties within the species *P. graminis.*

22. As the entities in the stem rust fungus now designated as varieties are specialized largely to different genera of Gramineae, whereas the physiologic forms of the varieties *tritici, avenae,* and *secalis* are differentiated by hosts within the genera *Triticum, Avena,* and *Secale* respectively, there seems to be sufficient warrant for regarding the former entities as of higher taxonomic rank than the physiologic forms. There is further justification for this procedure in the case of *P. graminis tritici*: (a) because there exists a close agreement between the average of the means of the urediniospore dimensions of the eight physiologic forms of *P. graminis tritici,* thus far biometrically studied, and the means previously determined for the variety as a whole; and (b) because of the negative correlation obtaining between the long and the short diameters of the urediniospores of all the forms within the *tritici* group, regardless of cultural and environmental conditions—in other words, the morphogenic processes being characteristic for the entire group.

23. Other conditions being equal, the uneven quantitative distribution of the rust inoculum is a factor in the difference in the severity of infection on naturally susceptible varieties. Furthermore, the severity of a stem rust epidemic seems to depend on the degree of maturity and general con-

dition of the wheat plant at the time infection first takes place; it also depends indirectly on the type of soil, its topography, and fertilization.

24. The extent and severity of stem rust epidemics depend also on favorable weather conditions, such as suitable atmospheric temperature, plenty of precipitation and soil moisture, the right amount of dew fall at the critical moment, prevailing winds, and sufficient sunshine.

25. There is evidently a positive correlation between the mean temperature of the last two months of the growing season and the total rainfall during this period and the severity of stem rust infection on susceptible varieties. When the total precipitation fell below 2 inches, or the temperature was less than 60° F., no rust developed. Not more than 40 per cent of stem rust, as a rule, appeared at or below 62° F. Over 90 per cent of rust was observed only where the mean temperature ranged between 66° F. and 72° F. and the total rainfall exceeded 2.5 inches.

26. Inasmuch as the multiple correlation coefficient for the combined effect of temperature and rainfall during the last two months of the development of wheat on the intensity of stem rust epidemics exceeds only slightly +0.4, indicating a reduction in variability of less than 10 per cent, it is apparent that the totality of the other factors, essential for a successful epidemic, is of major importance. To determine mathematically the combined effect of all contributing factors, much more observation and experimentation is required.

27. The common barberry is a constant and persistent menace to the small grain crops of the spring wheat region, not only as a source of supply of immeasurable quantities of inoculum but possibly also as a breeder, and certainly as a propagator, of virulent physiologic forms of the stem rust parasite. Therefore *Berberis vulgaris* and its stem-rust-bearing allies should be eradicated with all possible haste and thoroughness.

28. The parasitism of the physiologic forms of *Puccinia graminis tritici* is but little and only temporarily affected by external conditions. That these forms originate through progressive adaptation to changing environment is not borne out by extensive experimentation. Intensive studies of their possible origin by means of mutation or through the processes of hybridization and anastomosis are now under way.

29. Resistant varieties apparently are effective and feasible means for overcoming the ravages of black stem rust. The choice of varieties will depend in each case upon their adaptability to local conditions and the market value they command, in addition to their resistance to stem rust and other diseases and pests.

30. In conjunction with the attempt to destroy the alternate host and the effort to secure desirable resistant varieties, serious consideration should

be given to judicious cultural practices, such as the use of early maturing sorts, adequate crop rotations, and proper fertilization methods, and to the possibilities of obtaining effective chemical remedies.

BUREAU OF PLANT INDUSTRY,
UNITED STATES DEPARTMENT OF AGRICULTURE,
IN COOPERATION WITH
AGRICULTURAL EXPERIMENT STATION,
UNIVERSITY OF MINNESOTA,
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EXPLANATION OF PLATE I

Classes of host reaction: Resistant (R), Susceptible (S), and Indeterminate (I), as indicated by different types of infection (0, 1, 2, 3, 4, and X), produced by physiologic forms of *Puccinia graminis tritici* on varieties of *Triticum spp.*

0.—Either no infection whatever, or pronounced hypersensitive flecks;

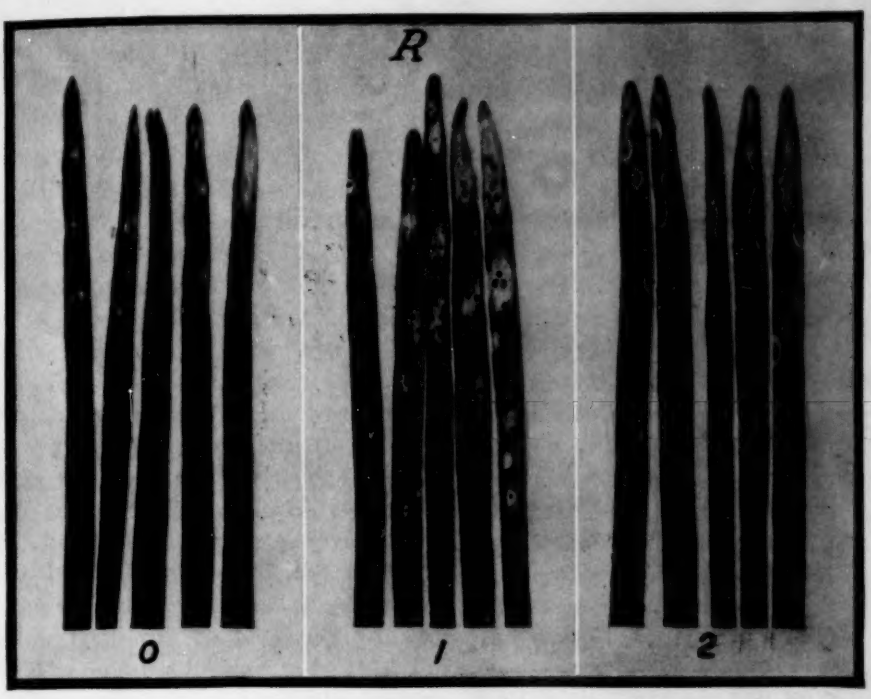
1.—Minute uredinia within solid necrotic lesions;

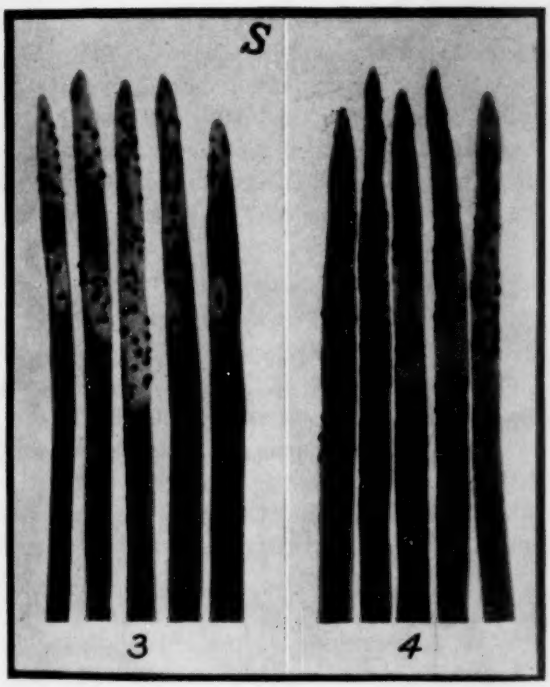
2.—Small pustules in green islands surrounded by necrotic halos;

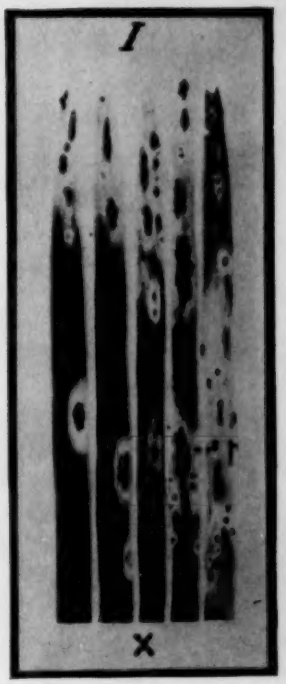
3.—Medium sized uredinia, slight chlorosis but no necrosis;

4.—Very heavy infection, large confluent uredinia;

X.—Infection heterogeneous and rather ill defined.







UNIV. OF MICH.

PHYTOPATHOLOGICAL NOTES

Emil Chr. Hansen-Medal, 1928.—Pursuant to the last will and testament of the late Professor Emil Chr. Hansen and his wife, a fund bearing his name has been established, the statutes of which were ratified by the Government on June 17, 1911.

At proper intervals, as a rule every two or three years, beginning in 1914, a Gold Medal bearing his effigy and accompanied by a sum of at least 2,000 Kroner is to be awarded on the donor's birthday, the 8th of May, to the author of a distinguished publication on some microbiological subject that has appeared in recent years in Denmark or elsewhere.

The fund is committed to the administration of the chiefs of the two departments of the Carlsberg Laboratory, together with a Danish biologist elected by the governing body of the Carlsberg Laboratory.

The person to whom the medal is to be assigned shall be designated by a committee composed of the above-mentioned trustees of the fund and at least two foreign microbiologists who, at the request of the said trustees, have declared themselves willing to act on the committee.

The medal was awarded in 1914 to Professor Dr. Jules Bordet, Brussels, for researches in medical microbiology; in 1922 to Professor Dr. M. W. Bejerinck, Delft, for researches on general microbiology; in 1923 to Dr. E. I. Allen, Plymouth, for researches in marine microbiology.

In 1928 it is proposed to award the medal to an author of bacteriological or mycological phytopathology.

Dr. O. Appel, Dahlem b. Berlin, and Professor Johanna Westerdijk, Utrecht, have been made members of the committee.

All the communications regarding the fund should be sent to the President of the Board of Trustees.

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Professor S. P. L. Sørensen, Ph.D. and M.D., Chemical Department of the Carlsberg Laboratory, Copenhagen, President of the Board of Trustees —S. P. L. SØRENSEN, *Copenhagen-Valby, Denmark.*

First Report of the Occurrence of Black Scab or Warty Disease of Potato in Belgium.—Black scab or warty disease of potato was found in two places in Belgium at approximately the same time during the season of 1927: at Courcelles in the province of Hainaut and at Stavelot in the province of Liège.

In both cases the disease was found in the small holdings of laborers, where potatoes are grown year after year on the same plots for home use.

The competent services of the Ministry of Agriculture have immediately taken all measures required.—E. MARCHAL, *Gembloux, Belgium.*

ABSTRACTS OF PAPERS PRESENTED AT THE NINETEENTH ANNUAL MEETING OF THE AMERICAN PHYTOPATHOLOGICAL SOCIETY, NASHVILLE, TENN., DECEMBER 28, 1927, TO JANUARY 1, 1928

Overgrowths and hairy root on nursery apple and quince trees. J. H. MUNCIE and W. B. SHIPPY.

Isolation trials from 111 grafted apple trees with hairy knots at the union failed to yield *Pseudomonas tumefaciens.* In similar trials on 58 trees showing the fibrous form of hairy root in the absence of an overgrowth, the pathogen was recovered in four cases from the swollen bases of the hairy roots, and from one of 100 apple trees showing the burr-knot type of hairy root on the stock, but not from 20 quince trees and 15 rooted quince cuttings. Typical hairy roots were induced at the nodes of 15 quince cuttings by rooting under aseptic conditions.

Of 2,200 apple seedlings inoculated in the field 7 per cent produced galls. Isolations from representative specimens were positive.

Overgrowths with fleshy hairy roots developed on 0.4 per cent of two lots each of 2,400 wounded seedlings grown in two plots of field soil non-infested and infested with *Ps. tumefaciens,* but the pathogen was not recovered. Hairy roots in the absence of overgrowths developed equally on wounded and unwounded seedlings in infested and non-infested soil. Isolations from seedlings showing either hairy roots or woolly knots were negative.

Isolation studies of burr-knots were made from specimens of 24 varieties of apple from four states. Rarely were organisms found resembling *Ps. tumefaciens.* These were not pathogenic tomato plants. Field observations show that, while certain environmental conditions favor the production of burr-knots, certain varieties have never shown them. Certain varieties showing no burr-knots, when cross-pollinated, produced hybrids bearing aerial tumors at an early age.

Grafting as a further means of preventing callus knots on apple. I. E. MELHUS, J. H. MUNCIE, and VERNON C. FISK.

In a graft with an overhanging scion tip, excess callus first forms as a knot from the severed cambium of the scion, later growing backward, filling the space between stock and scion. The phellogen layer is soon differentiated in the callus. This cuts off and causes the death of the outer layer of proliferating cells of the scion callus. The slower growing stock callus finds no meristematic cells with which to unite, and lack of continuity in the union results. Further growth of the callus knot results from the laying down of phloem and xylem by the cambium layer differentiated in the callus. These facts coupled with field observations showing that approximately 60 per cent of the overgrowths at the union of piece-root grafted trees occurred at the tip of the scion lip led to trials of the wedge or cleft graft as a means of holding the scion lip in place and thus preventing knot formation.

Storage trials were made in which wedge and tongue grafts of the variety Wealthy were callused at low, medium, and high temperatures. The wedge grafts showed an average of 75 per cent less callus knots than the tongue grafts. In nursery field trials one-year-old, wedged-grafted trees of the variety Whitney had 4 per cent with callus

knots; while 28 per cent of those from tongue grafts were knotted. At the end of two years the remaining 362 wedge- and 348 tongue-grafted Whitney trees were dug. Of the wedge-grafted trees, 8.1 per cent showed callus knots, and of the tongue grafted 32.8 per cent. In both cases the majority of the knots developed at the tip of the scion lip.

Studies of the history of development of wound overgrowths on apple grafts and of the influence of wrappers on their suppression. A. J. RIKER, W. M. BANFIELD, and G. W. KEITT.

Frequent observations of apple grafts throughout the first season showed that certain enlargement began to develop very early as the direct result of poor union. These are rather easily controlled by good fitting and wrapping. Enlargements were also observed to be initiated during or after midseason on any part of the union. The development of certain of these seems to have been correlated with periods of rapid secondary thickening.

The duration of strength of wrappers in the soil has been shown to affect the development of wound overgrowths. Studies were made of various wrappers, with the following results: (1) by chemical treatments cotton thread was made to endure for any desired period; (2) girdling ensued in Wisconsin from wrappers which lasted more than 11 weeks; (3) typical wound overgrowths followed girdling; (4) uneven application considerably lengthened the durability of wrappers; and (5) of the wrappers used, medical adhesive tape gave the highest percentage of salable trees. A series of experiments in Wisconsin, Minnesota, Nebraska, Missouri, and Oklahoma involving trials during three years has consistently shown that grafts wrapped with an adhesive tape produced a considerably higher percentage of salable trees than those wrapped with string.

Correlation of the wound overgrowth and crowngall of apple in parts of Europe and of the United States. A. J. RIKER.

A survey was made in certain nurseries of England, France, and Holland in order to correlate the wound overgrowth and crowngall situations in these regions with those in the North-central and Northeastern United States. While examining the results of this survey one must hold in mind such considerations as the following: (1) that this part of Europe has a comparatively mild climate with a long growing season; (2) that the market requires a very high percentage of dwarfed trees; and (3) that practically all fruit trees are propagated by budding. As in America, the practice of budding has practically eliminated wound overgrowths from the plants except as these developments follow injuries to the stock. Bacterial crowngall was found widely distributed but of no economic significance except in a few isolated cases. On the other hand the common practice of employing Paradise and Doucin stocks for the growth of more or less dwarfed apple trees made burr-knots very common. Likewise, enlargements at the union several inches above the soil line, which were attributed to lack of congeniality, were quite usually present on dwarfed stock.

Studies on the life history of the crowngall organism. W. M. BANFIELD.

Studies are being made of various phases of the life history of *Bacterium tumefaciens* in relation to raspberry crowngall.

The pathogen, as previously reported by other workers, has been found in very large numbers in tissue removed aseptically from the interior of crowngalls. In many cases masses of the bacteria have been observed on the surface of galls. They have

been obtained in considerable numbers from water in which galls had been placed for a short time. Thus it appears that crowngalls may be a continual source of inoculum to the surrounding medium.

The pathogen has been found to live in different types of unsterilized soil for periods varying from a few months to over a year, and to overwinter in soil in the field at Madison, Wisconsin. As in all cases mentioned in this abstract, the identity of the organism was established by isolation in pure culture and successful inoculation into tomato.

Experiments as to the mode of penetration of the pathogen into disease-free raspberry plants grown in infested soil have shown that wounds are important avenues of entrance, and have suggested that both chewing insects and growth characters of certain varieties of raspberry may play important rôles in infection.

The method and rate of migration of Bacterium tumefaciens in tomato. J. BEN HILL.

Vigorous healthy young stems of tomato were inoculated with *Bacterium tumefaciens.* Study of properly stained paraffin sections of this material secured within three hours after inoculation shows that the bacteria migrate as zoogloeae or zoogloeal strands through the inter-cellular spaces of the pith and subepidermal chlorophyllose parenchyma. The zoogloeae apparently consist of semi-fluid gelatinous matrix densely packed with bacteria. The ends of the zoogloeal strands are blunt and rounded. Zoogloeal strands are continuous for from 0.35 to 0.56 mm. and continuous but for slight interruptions for much greater distances. Over 80 distinct zoogloeae were measured and their rate of migration calculated. Rates of movement of the zoogloeae of 0.04 mm. per minute for the first 15 minutes and of approximately 0.03 mm. per minute for three hours were calculated. The maximum rate of migration of the zoogloeal strands, while comparatively rapid, is only one twenty-fifth of the published calculation of the rate of a single motile *B. tumefaciens* in liquid medium.

Longevity of Pseudomonas tumefaciens Sm. & Town. in various soils. M. K. PATEL.

In the laboratory *Pseudomonas tumefaciens* was reisolated after 16 months from sterilized clay, loam, and quartz sand, which were artificially infested. The number of colonies on agar poured plates of crystal violet bile decreased as the time increased. No difference in the number of colonies were found in plates from loam and clay.

Pure cultures of the pathogen were also obtained from non-sterilized infested sand after 16 months and from clay and loam after 14 months. This decrease in longevity may be due to the fact that the pathogen had to compete with a greater number of soil organisms in loam and clay than in sand. The unsterilized and sterilized samples of infested loam kept in the open from October to March yielded virulent cultures of the pathogen. The samples of unsterilized and sterilized infested clay loam and quartz sand, buried 12 inches in the soil from November to March, gave pathogenic cultures of the crown gall bacteria. Field soils of the loam type infested in late fall with a 72-hour broth culture of the pathogen and finely chopped tomato galls yielded the pathogen the following March.

Strains of Pseudomonas tumefaciens Sm. and Town. and their prevalence in various soils. M. K. PATEL.

Further studies were carried out on 15 non-pathogenic strains of *Pseudomonas tumefaciens.* Sm. and Town. These strains and a pathogenic one gave practically the same titre when tri- and tetra-valent salts were used in agglutination tests. Six of these

non-pathogenic strains and the one pathogenic strain had one, two, or three polar flagella. The pathogenic strains always, and the non-pathogenic ones never, produced crown galls on sweet peas, garden peas, oleander, bryophyllum, raspberries, weeping willows, and apples. One pathogenic strain which was identical in all other respects with the other pathogenic strains lost its virulence after being cultured two years on common medium.

Using the author's crystal violet bile medium, plates were poured from various soil samples. From 41 of the 96 samples collected in 12 nurseries in 9 states, organisms resembling *Pseudomonas tumefaciens* were obtained. Seven of these organisms proved pathogenic on tomato plants. Only one non-pathogenic colony which resembled *Pseudomonas tumefaciens* was obtained from another lot of 14 samples taken from pasture and corn land, virgin prairie, and nursery fields on which no crown gall susceptible crops had been grown for many years.

Repeated isolations from water and air gave no colonies resembling *Pseudomonas tumefaciens*.

Studies on crown gall transplants. MICHAEL LEVINE.

Pieces of crown gall tissue of *Ricinus communis*, when transplanted into the same and other Ricinus plants, produce small crown galls in most cases.

Ricinus crown gall tissues, when transplanted to growing portions of the tobacco plant, also produce galls. Similar results were obtained with crown galls of tomato, geranium, and beet. These neoplasms are generally of the host type. The crown gall on the tobacco, induced by an inoculum of tomato or Ricinus crown gall, becomes differentiated and forms leafy shoots with characteristic tobacco leaves.

Small, maroon-colored pieces of sugar beet crown gall transplanted to the yellow mangel produce a relatively large number of yellow pigmented crown galls. In a few cases only, there is indisputable evidence of the growth of the inoculum. There are also distinct proliferations of the host, as shown by gross sections of the tumor.

These studies show that the crown galls are not generally formed as the result of the growth of the transplanted tumor issue itself, but follow the introduction of *Bacterium tumefaciens* with the inoculum. Plate cultures of parts of the inocula used yielded *B. tumefaciens*, as determined by cultural studies, smears, and subsequent inoculations.

Rumex crispus, a weed host of Pseudomonas tumefaciens. J. H. MUNCIE.

In June, 1926, a plant of *Rumex crispus* L. with a large overgrowth at the crown was taken by Dr. O. H. Elmer from a field of raspberries in Minnesota, some plants of which were infested with crown gall. Isolations were made from the gall, and *Pseudomonas tumefaciens* was recovered in almost pure culture. Inoculations from these plates into healthy young tomato plants resulted in the production of typical crown galls. Further inoculations into *Rumex crispus* with strains of *Ps. tumefaciens* from *Rumex* and raspberry resulted in the formation of galls in all cases.

As far as the writer is aware, this is the first report of crown gall occurring in nature on a species of *Rumex*. This suggests the possibility of infected perennial weeds as a means of carrying over the crown gall in fields planted to non-susceptible crops.

The effects of lime on cigar tobacco. C. M. SLAGG, J. E. MONTREUIL, and T. G. MAJOR.

The effects of air-slaked lime at the rate of 2,000 pounds an acre in combination with manure; with commercial fertilizers; and with commercial fertilizers and manure

have been studied on cigar tobacco at the Farnham, Quebec, Experimental Station in 1925, 1926, and 1927. The field used had grown several crops of tobacco previously in a three-year rotation of oats, clover, and tobacco. The soil was free from Thielavia root rot at the beginning of the experiment. After three years of continuous tobacco culture a moderate infestation of *Thielavia* was present. It was more marked on the limed plots. Significant decreases in yield and quantity were secured wherever lime was applied during each of the three years of the experiment.

Soil reaction and black root rot of tobacco. P. J. ANDERSON.

Black root rot (*Thielavia basicola*) is present in all old tobacco fields of the Connecticut Valley, irrespective of reaction. Severe reduction in yield, however, occurs only in soils which approach the neutral point. Injury below pH 5.6 is practically negligible. Practically all old fields with a reaction about pH 6.0 are suffering from root rot; the higher the reaction, the smaller the growth. In the "doubtful zone" between pH 5.6 and pH 6.0 there may be no injury or it may be present in varying degrees, as influenced by other characters of the soil and the season. A rapid soil-testing technique has been developed and is being used extensively by the growers in choosing fields to be set to tobacco each year.

The influence of cropping systems and fertilizers on black and brown root rot of tobacco. J. P. JONES.

Different cropping systems have not influenced black root rot of tobacco; but have affected the brown root rot, the extent depending upon the other crop grown in the rotation. In the animal-husbandry rotation, tobacco, following either hay or corn, was so severely attacked by the brown root rot as to cause low yields. Tobacco grown in the money-crop rotation after onions or potatoes, or in continuous culture without a cover crop, was damaged but little by brown root rot. Timothy as a cover crop induced brown root rot and reduced the yield. Tobacco grown every year on the same land and without a cover crop showed the least injury by brown root rot and the best yields.

Black root rot has been found to do no damage on soils more acid than pH 5.95. When the soil was made less acid than this by liming, this disease became harmful. Phosphoric acid also acted as a stimulant to black root rot in a soil already badly infested, but it did not act in this manner on an acid soil. Carbonate of potash, to furnish the amount of potash required for tobacco, when applied to acid soils, has not influenced black rot. Little evidence has been obtained to show that brown root rot is affected by fertilizers.

Effect of timothy infusion of different ages on the growth of tobacco and on brown root rot of tobacco. W. L. DORAN.

When decoctions of timothy in water were applied to soil in which tobacco plants were growing, the effect on the plants was either stimulatory or inhibitory, depending on the age of the decoctions. Infusion of whole timothy plants, kept at about 27° C., aged 1 to 3 weeks, did not inhibit growth of tobacco and did not induce brown root rot. But these infusions, when 4 to 10 weeks old, produced on tobacco the symptoms of brown root rot and greatly inhibited growth. Dry weights of plants receiving timothy infusions 4 to 8 weeks old were 2 to 33 (relative numbers) as compared with 100 in checks. Infusions 9 to 10 weeks old were less toxic, dry weights of corresponding tobacco plants being 61 to 77 (relative numbers).

In another experiment, timothy decoctions were made with most of the tops removed and were kept at about 16° C. Under these conditions, infusions 1 to 6 weeks old did

not induce brown root rot and greatly improved the growth of the tobacco plants. But when these infusions were 7 to 12 weeks old their application resulted in symptoms of brown root rot. When infusions were 10 to 12 weeks old the growth of the plants was reduced fully 50 per cent.

Accuracy in comparing various concentrations of tobacco-mosaic virus. FRANCIS O. HOLMES.

An investigation of ultraviolet light photography applied to plant viruses emphasized the desirability of knowing whether the small amounts of fluid represented in the photographs could be expected to contain as much as, or more than, one effective unit or the active agent.

By carrying virus from expressed juice or diseased plants to small healthy plants by single inoculations with fine No. 00 black enamel insect pins, minute quantities of juice are transferred, and transmission is secured regularly enough to allow quantitative studies. Two factors are believed responsible for the uniformity of the readings, i. e., uniform wounding, and deposit in the wound of a large proportion of the transferred virus. Small test plants, 50 in a flat, were employed, thus insuring numerous determinations. To adjust the dosage, and facilitate inoculation, several insect pins may be mounted in one handle and used simultaneously.

The method is so accurate that test dilutions of 1:4 or 1:8 can be identified from undiluted samples of virus with a certainty corresponding to odds of 22 to 1 or more. Similarly adjacent portions of infected plant tissues can be identified and accurate readings made with no more than 1,000 seedlings. Equally accurate comparisons of sources differing even less in strength can be made by using larger numbers of plants.

Experiments and observations on the control of true tobacco mosaic. W. D. VALLEAU and E. M. JOHNSON.

In a rotation series in which 13,000 plants are set each year, mosaic counts, made about three weeks after setting, for three consecutive years, showed 9, 6, and 8.7 per cent mosaic, respectively, when plants were pulled by men chewing natural leaf tobacco. The next year, when the men chewed mostly commerical tobacco, the percentage was 2.1. The two following years, when sterilized tobacco was chewed, the percentages were 0.44 and 0.05 respectively. The third year the hands were washed before the pulling was begun. Last season (1927), using these precautions, 32 mosaic plants developed in 71,183 plants set. A survey study of the relationship between chewing habits of workers and percentage of mosaic gave the following results:

3.10 per cent mosaic in 100,993 plants pulled by uncleanly worker who chewed tobacco.

0.64 per cent mosaic in 12,515 plants pulled by cleanly worker who chewed tobacco.

0.55 per cent mosaic in 20,963 plants pulled by worker who did not chew tobacco.

Of 134 plants pulled by a man who chewed viruliferous natural-leaf tobacco and occasionally spit on his hands while pulling, mosaic developed on 108; while 156 plants pulled with clean hands were healthy 47 days after setting. When no effort was made to contaminate the worker's fingers, 878 plants developed 39 cases of mosaic. When 837 plants were pulled with clean hands and set in alternate rows, but one case of mosaic developed in 48 days.

Some virus diseases of tobacco in Kentucky. W. D. VALLEAU and E. M. JOHNSON.

Four apparently distinct strains of true tobacco mosaic have been obtained from tobacco in Kentucky. Mild and severe strains have been carried through two years and

have remained distinct. Recently a milder and a more severe form were found. Virus diseases of tobacco, distinct from mosaic, and common near Lexington, are: "ring-spot," which has been transferred from naturally-infected tobacco, a bull-nettle, and cucumbers to tobacco, but not from ring-spotted delphinium and peony; "Coarse-etched," a disease somewhat similar to ring-spot; "Puffed," which has been transferred from naturally infected tobacco, cucumbers, muskmelons, and milkweeds to tobacco (possibly cucumber mosaic); "Etched," characterized by chlorotic dots in the growing point and a fine etched necrotic pattern on some of the leaves; "Etched+," evidently a severe strain of etched; and "Vein-margin," which may be a very mild strain of etched. It causes slight spotting in the growing point and a general mild chlorosis of some of the older leaves, except in the tissue immediately adjoining the veins, thus leaving a dark band along the small veins. These diseases are not so prevalent as tobacco mosaic, but, where present, they appear to spread as rapidly by natural means and to be equally injurious.

Tobacco ringspot; a virus disease with a wide host range. S. A. WINGARD and F. D. FROMME.

Further studies of tobacco ringspot have shown it to be a virus disease capable of infecting a wide range of plants. Infection has been obtained on 19 genera of plants representing the following 11 families: *Solanaceae, Compositae, Leguminosae, Phytolaccaceae, Violaceae, Amaranthaceae, Chenopodiaceae, Polygonaceae, Convolvulaceae, Plantaginaceae, Aizoaceae.* There is some evidence that the green aphis may transmit the virus in the greenhouse, but insects are not necessary for infection, for it is readily accomplished when trial plants are swabbed with the expressed sap of diseased plants. The sap has been found infectious in dilutions as high as 1 in 10,000 but not in higher dilutions.

Cucumber fruit-rot and angular leaf-spot. GEORGE F. WEBER.

During the past five years, observations have been made and data collected in Florida on the occurrence and association of these two diseases of cucumbers, caused by *Bacterium lachrymans* E. F. S. and Bry., which have appeared in the state each year to a greater or less extent. The data show that angular leaf spot in the field may or may not be accompanied by fruit rot, and that fruit rot is always accompanied by angular leaf-spot. In fields planted with seed disinfected for 10 minutes with 1:1000 corrosive sublimate the disease did not develop on leaf or fruit, but the disease appeared in 75 per cent of fields planted with untreated seed.

Two bacterial organisms isolated from diseased cucumber leaves and fruits collected near Gainesville, Florida, were used to inoculate cucumber leaves and fruit under controlled conditions. The organism isolated from leaves produced both the angular spot on leaves and the characteristic fruit-rot; and the organism isolated from fruit produced both the fruit rot and the angular leaf-spot. The two organisms show as much similarity in pure culture as two transfers of the same culture. These studies indicate that a single organism causes both the leaf spot and fruit rot of cucumbers as discovered by O. F. Burger.

Preliminary report on a new leaf spot of pecan. O. C. BOYD.

In 1926, in several pecan orchards near Albany, Georgia, a characteristic leaf spot was observed that had not previously been reported. It was observed in 1927 in practically every pecan section surveyed in the southern part of the state.

It was more common in orchards than in nurseries. The following varieties, listed in the order of their susceptibility, have been found affected: Delmas, Moneymaker, Stuart, Frotcher, Van Deman, Schley, Alley, Mobile. Common varieties observed not attacked are Moore, Success, Tesch, and Pabst.

The trees are injured by premature, partial defoliation. The spots when young are pale yellow in color, later turning to yellowish brown, or perhaps brown to black, depending on the variety concerned. Conidia are produced in from one to many minute ascervuli on the underside of the lesion, forming under certain conditions a mildew-like or downy coating over the spot.

The causal organism, while resembling to some extent both a *Cylindrosporium* and a *Cercosporella*, does not seem typical of either of those genera. Demaree and Cole consider the fungus identical with *Cylindrosporium caryigenum* Ell. & Ev., described as occurring on *Carya amara*, and collected in Canada in 1899. (Plant Disease Reporter, Vol. 11, No. 11, 1927.

Cotton seed treatment by the dusting method. NAOMI CHAPMAN WOODROOF.

At the Georgia Experiment Station treating undelinted cotton seed with fungicidal dusts has been found to be economical and much simpler than the standard method of delinting with sulphuric acid and soaking for 30 minutes in mercuric chloride. Of the numerous dusts tested several have been found capable of surface-sterilizing the seed. Mercuric resinate and a combination mercuric chloride dust are equally as effective as the standard treatment. Angular leaf spot was very much reduced by seed disinfectants. Yields have not been materially increased by any of the treatments. Further work is necessary before definite recommendations can be made.

Outstanding wilt-resistant cotton varieties. D. C. NEAL.

Wilt-resistance tests were made in 1926 and 1927 with 18 varieties and selections of staple and short cottons on soil which had been artificially inoculated so as to insure more complete exposure of the plant roots to the wilt fungus, *Fusarium vasinfectum*. Since these experiments have been in progress, considerable difficulty has been experienced in finding resistant varieties which yield well under varying conditions. Sometimes a variety is very resistant to wilt, but may not be polific, or is late maturing, or unsuitable for areas where the boll weevil is a serious factor.

A list of both staple and short cotton varieties which have shown considerable resistance in the tests during 1926 and 1927 and which have produced well on wilt-infested soil is given below with the source of the seed.

WILT-RESISTANT STAPLE COTTONS

Super-Seven .....Coker Pedigreed Seed Company, Hartsville, South Carolina.
Lightning Express .....Humphrey-Coker, Hartsville, S. C.
D. & P. L. No. 6 .....Delta & Pine Land Planting Company, Scott, Mississippi.
Watson's Long Staple.....L. O. Watson, Florence, S. C.

WILT-RESISTANT SHORT COTTONS

Cook, Rhyne .....Rhyne Bros., Benton, Alabama.
Dixie-Triumph .....L. O. Watson, Florence, S. C.
Miller .....Miss. Experiment Station, A. & M. College, Miss.
Cleveland 54 .....Miss. Experiment Station, A. & M. College, Miss.
Triumph, Willis .....Hinds County Farm Bureau, Jackson, Miss.

The use of resistant varieties and liberal fertilization of the crop with balanced fertilizers are considered to be the most feasible and economical means of controlling the disease.

The gummosis of sugar cane. MELVILLE T. COOK.

Gummosis of sugar cane is a vascular disease caused by *Bacterium vascularum* E. F. S. Some varieties of cane are very susceptible while others appear to be immune. Some varieties are killed out by the organism and in others the yield is very much reduced. It is said that the cell walls are dissolved, but our studies indicate that this is rare and occurs only in young tissues. The tracheary tubes are filled with the organism, which is frequently abundant also in the parenchyma. In the mills, gummosis causes a lowering a purities and interferes with crystallization. The leaf symptoms are unreliable, as they do not always appear on diseased cane and similar symptoms due to other causes are sometimes found on healthy cane. Field experiments show that the disease spreads readily from row to row. On plantations it is probably carried mechanically. No insect carriers have been discovered in Porto Rico.

Sugar cane eye spot in Cuba. JAMES A. FARIS.

Two distinct leaf spots of sugar cane due to different species of *Helminthosporium* occur in Cuba. Eye spot, present in Western Cuba since 1915, appears to have been re-introduced recently into Eastern Cuba from Porto Rico. It injures susceptible varieties seriously, producing reddish spots surrounded by a lighter halo and progressing to the edge of the leaf by long, reddish, broad bands. The cane varieties D 109, F. C. 137, F. C. 214, and F. C. 306 are too susceptible for commercial growing. More resistant are Badila, Cristalina, Java 105, Java Unknown, and Uba. Environmental conditions greatly influence the development of eye spot, cane in localities with high humidity, as in low, foggy valleys, being worst affected. This common eye spot, a major disease of sugar cane, has been reported from Hawaii, Fiji, Australia, Formosa, The Philippines, Java, India, Mauritius, Cuba, and Porto Rico. No evidence of it was seen during recent visits to Louisiana and Florida, and it probably does not yet occur in the Southern United States.

Brown stripe of sugar cane in Cuba. JAMES A. FARIS.

Brown stripe of sugar cane, caused by a species of *Helminthosporium*, different from that causing eye spot, attacks Cristalina cane throughout Cuba, appearing as minute, reddish spots which elongate to form characteristic linear stripes surrounded by slight halos. This previously has been considered an immature stage of the eye spot described in the preceding abstract. That the two diseases are not the same has been demonstrated by inoculating many plants both under bell-jars and grown in glass cylinders under sterile conditions. The two types of spots can be distinguished in their early stages. The causal fungi also have distinct characteristics in growth on various media and in spore morphology. A similar brown stripe was observed in Louisiana and Florida the summer of 1927, and the causal fungus may be the same as that named *H. stenospilum* by Drechsler. Slow growth seems to favor the development of brown stripe, its prevalence being most marked during long dry periods in the summer and latter part of the winter.

A species of Helminthosporium distinct from Helminthosporium sacchari, causing brown stripe of sugar cane. CHARLES DRECHSLER.

Diseased sugar cane specimens collected over several years in Georgia, Florida, and Cuba reveal two species of *Helminthosporium* causing foliar injury. Lesions in some Cuban material appearing as elliptical reddish-brown spots, in well developed instances often 20 mm. long and 3 mm. wide, with somewhat bleached central and zonal markings, yield under moist conditions a fungus producing fuliginous conidia with thin peripheral

wall and 3 to 10 septa (average 6.7), measuring 32 to 103 μ in length (average 71 μ) by 9 to 17 μ in width (average 14 μ). Under similar conditions lesions in leaves from Georgia, Florida, and Cuba, appearing first as very narrow, linear brown streaks, later often becoming more extensive through enlargement or coalescence without conspicuous internal markings, yield a form producing dark olivaceous conidia with thick peripheral wall and 3 to 12 septa (average 7.7), measuring 40 to 128 μ in length (average 83 μ) by 12 to 22 μ in width (average 17 μ). The first-mentioned fungus from lesions of true "eye-spot" type is the one more aptly identified as *H. sacchari* Butler; the second, associated with "brown stripe," and distinguished by its much darker, thicker-walled, broader spores, is provisionally named **H. stenospilum** n. sp.

The effect of disinfectants upon the germination of seeds kept in storage for indefinite periods after treatment. C. R. ORTON.

The seed of several varieties of wheat, oats, sweet corn, field corn, and beans which were treated with chemical disinfectants in liquid and dust form at various dates from November, 1924, to Novmber, 1926, and stored at 20–22° C. were germinated October, 1927, in greenhouse soil and two sets of comparisons made—(1) with the germination of untreated seed of the same source, (2) with the germination of the same lots of treated and untreated seed at the approximate date of treatment.

The organic mercury dusts did not decrease germination and often increased it after periods of one to three years. Copper carbonate dusts were injurious on Navy and Black Valentine Beans. Dusts composed of $HgCl_2$ and oxide of copper caused decreased germination in some cases. Liquid treatments with organic and inorganic mercuries and water are more likely to be injurious, water being especially so. Formaldehyde was especially injurious to oats.

A bacterial disease of broad beans. A. J. RIKER.

Studies were made in England of a bacterial disease of broad beans. An organism was isolated consistently and in large numbers from lesions commonly called "chocolate spots." Two strains of this organism were run through the cycle of isolation, inoculation, infection, and reisolation five successive times each. Typical symptoms developed under certain conditions following inoculations in the greenhouse. When all conditions were favorable, such as temperature between 20° and 30° C., relative humidity approaching saturation, plants vigorously growing, and cultures actively motile, plants were killed in three days. The cultures were also vigorously pathogenic to garden peas.

The organism grows rapidly on ordinary media. Nutrient agar colonies after five days are circular, radiately ridged, umbonate, undulate, and granular. When the medium contains considerable water and dextrose, the colonies tend to become rhizoid. According to the 1924 chart of the Society of American Bacteriologists this organism has the numbers 5011, 32100, 0202. A non-pathogenic organism having the same number was found in association.

Histological studies showed that the organism multiplied rapidly inside the tissue and occupied primarily an intercellular position. After inoculation the bacteria sometimes spread rapidly in the vascular elements.

Irrigation as a cause of white spot of alfalfa. B. L. RICHARDS.

White spot frequently becomes a serious factor in alfalfa production in Utah. The nature and cause of this disease has remained obscure and, although various theories as to its etiology have been advanced, no experimental data have been presented in support

of any of them. Recent studies indicate clearly that the trouble is in some way associated with an unbalanced water relationship in the plant which may readily be induced, under certain conditions, by the application of irrigation water. During 1926 and 1927 white spot was experimentally produced over a considerable acreage and to an extent of 75–80 per cent of the plants in certain fields. These experiments were so controlled and were repeated in such numbers as to justify the conclusion that, while other factors might be responsible under local conditions for the production of white spot, the improper application of irrigation water is by far the most important cause of the disease in the West. Surveys conducted preceding and subsequent to the experimental work confirm this conclusion and indicate that heavy rains may also be responsible at times for this disease.

The production of similar, if not identical, lesions in the leaves of sweet clover (*Melilotus alba*) in the same field and under the same experimental conditions responsible for the white spot of alfalfa indicated that such localized mesophyll destruction is not peculiar to alfalfa.

Mercury as a control for turf diseases. JOHN MONTEITH, JR., and A. S. DAHL.

Experimental work on control of large brown-patch (*Rhizoctonia solani*) and small brown-patch (*Rhizoctonia sp.*) of turf was continued at the Turf Garden, Arlington Farm, Virginia. The results substantiated those previously reported; namely, a large number of both organic and inorganic mercury compounds are, with the exception of the sulphide, effective against these diseases, their effectiveness depending chiefly on the mercury content. Preliminary tests with metallic mercury, mixed with chalk, indicated that mercury in this form gave as good results as when applied in a chemical compound. Observations again failed to disclose any injury to turf due to an accumulation of mercury in the soil similar to that found with copper. On the other hand, applications of mercury to a soil may prevent an attack of disease for weeks or even months. A heavy application of calomel August 31, 1926, prevented small brown-patch until the following August. Corrosive sublimate put on in October, 1926, at Madison, Wisconsin, likewise prevented attacks of snow mold during February and March, 1927. Calomel was again found to give longest protection per unit of mercury, to be least likely to burn, but slower in checking an active case of brown-patch. Mercury compounds may be combined with fertilizers used in ordinary green maintenance without impairing the fungicidal or fertilizing properties.

Leafhopper injury of legumes. JOHN MONTEITH, JR.

Experiments in insect-proof cages at Arlington Farm, Virginia, demonstrated that potato leafhopper (*Empoasca fabae*) injury occurs on most of the leguminous forage crops, as well as on common beans. Symptoms identical with those observed in the field developed in hopper-infested cages; whereas plants in hopper-free cages remained vigorous and healthy. In all infested plants there is a dwarfing of the vegetative parts and a reduction in floral development. Tip and marginal burning of leaves is a common symptom among the legumes. Some plants, as *Melilotus*, suffer comparatively little discoloration of the leaves; while others, such as clovers, show pronounced yellowing or reddening, especially at the tips and margins. Beans, cowpeas, and soybeans, in addition to the yellowing and burning symptoms, show a crinkling and curling of the younger leaves resembling that described on beans inoculated with curly-top virus. Entire plants are frequently killed, but usually the injury is localized. Even badly injured plants may recover entirely. Although probably not of the virus class, this damage is apparently caused by something more than the mere mechanical injuries due to penetration and

sucking. Striking differences in varietal susceptibility were observed in all the crops under observation. Resistance appears to be due to some quality in the host plant which makes it less favorable for the feeding and reproduction of the leafhoppers.

The effective methods of eradicating Rhamnus species susceptible to Puccinia coronata Corda. S. M. DIETZ and L. D. LEACH.

Rhamnus cathartica and *R. lanceolata* have initiated local epidemics of crown rust in the Upper Mississippi Valley during 11 of the past 12 years. Table 1 shows four effective methods of eradicating *R. lanceolata*, i. e., application of salt to base of plant; application of kerosene to base of plant; application of salt following removal of top growth; and removal of the crown. One hundred and thirty-five individual bushes were treated by the first, 105 by the second, 25 by the third, and 67 by the fourth method.

TABLE 1.—*Effective methods of eradicating Rhamnus lanceolata.*

Area of cross-section of main stems in sq. in.	Bush standing		Top growth removed	Crown removed
	Pounds of salt	Quarts of kerosene		
1–2	2½	½		
2–5	5	1	Chopped off and 2½	No additional
5–15	10	2	pounds salt added	treatment
15–35	15	3	Chopped off and 5	
35–55	20	4	pounds salt added	
55–125	25	5		

The response of *Rhamnus cathartica* to salt and removal of the crown was similar to that of *R. lanceolata*.

Seasonal effect on rate of killing *Rhamnus lanceolata* was shown by the fact that bushes treated with salt in March died on an average within 66 days; those treated in July, within 98 days; those in August within 162 days. It required an average of 110 days to kill the bushes treated with kerosene in March, 77 for those treated in July, and 109 for those in August. (Cooperative investigations by the Iowa Agricultural Experiment Station and the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture.)

Inheritance of resistance to Puccinia sorghi in maize. E. B. MAINS.

Selections of Golden Glow 228, Golden Bantam 996, and Howling Mob 983 are resistant to physiologic form 1, of *Puccinia sorghi* and susceptible to physiologic form 3 in the seedling stage, while selections of Golden Glow 208 are resistant to both forms. The inheritance of the resistance of the selections has been studied in a number of crosses with varieties susceptible to both physiologic forms of the rust. The ratios obtained in the F_2, for the most part, closely approximate 3 resistant; 1 susceptible indicating a single factor pair in each case. A study of the inheritance of resistance in relation to endosperm color and texture, albinism, and anther ear dwarf has so far given no evidence of linkage with these characters. The same factor is apparently responsible for the resistance of selections of Golden Glow 208 to both physiologic forms 1 and 3. (Cooperative Investigations between the Purdue Agricultural Experiment Station and the Office of Cereal Crops and Diseases, United States Department of Agriculture.)

New physiologic forms of Tilletia tritici in wheat. E. F. GAINES.

In 1927 bunt appeared on hitherto immune strains of wheat at five different stations in Washington, Oregon, and Montana.

An experiment planned to test the comparative pathogenicity of *T. tritici* from Germany with that common to Eastern Washington showed unmistakable differences. The American wheats were much more susceptible to the German form, while the German wheats succumbed more readily to the American form.

Inoculation tests in Europe indicate that the so-called immune wheats of America are sometimes infected.

The gradual increase of bunt in America, especially in Kansas, Virginia, and Pennsylvania, during recent years may be due to new forms which are more virulent on the wheats commonly grown there. (Cooperative investigations by the Washington Agricultural Experiment Station and the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture.)

New dust treatments for oat smuts. J. D. SAYRE and R. C. THOMAS.

Two new dust treatments for the control of the smuts of oats were tried last summer with excellent results. One of the dusts was made by mixing formaldehyde with infusorial earth in different concentrations. This dust, when used at the rate of three ounces a bushel of grain, gave just as good control of the smuts of oats as did the wet-formaldehyde method. The formaldehyde-dust plots showed less than 0.2 per cent smut, while the checks averaged 47 per cent smut. The other dust was made by mixing finely ground solid iodine with infusorial earth. The iodine is quickly vaporized at ordinary temperatures and diffuses through the infusorial earth and is absorbed by it. When used at the same rate as the formaldehyde dust, only three smutted heads of oats were found in the three one-hundredth-acre plots. No injury to the grain resulted from either treatment. Further tests on the minimum concentration of the dusts necessary to control smuts of wheat and oats are under way. The cost of treating grain with these dusts is estimated at less than five cents a bushel.

Seed disinfectants for the control of covered smut and stripe of hulless barley. R. H. PORTER.

Extensive experiments were carried on at Nanking, China, in 1925 and 1926 with seed disinfectants for the control of covered smut and stripe of hulless barley. Liquid treatments used were Tillantin "B," and Uspulun 0.3 per cent solutions, cold formaldehyde, and hot formaldehyde. Dry treatments were copper carbonate, Tillantin "B," Uspulun, and powdered copper sulfate. In 1925, all treatments reduced the covered smut to less than 0.5 per cent, in rod rows. The checks had 7 per cent smut. In rod-square plots the checks had 27 per cent of smut and those treated with copper carbonate (54 per cent) had 1.2 per cent. In 1926 copper carbonate and dry Uspulun eliminated smut entirely; whereas dry Tillantin "B" gave 0.87 per cent. The checks averaged 6 per cent. The percentage increase in yield due to copper carbonate, Uspulun, and Tillantin "B" were 15.4 per cent, 12.4 per cent and 20.7 per cent respectively in 1926. Average yield of the checks was 13.0 bushels per acre. Plantings were in rod rows with 9 replications. Copper carbonate, Uspulun dust, and Tillantin dust, when used on stripe infected seed, reduced the stripe from 10.8 per cent in the checks to 5.5, 4.0, and 4.0 per cent respectively. Yield increases were 10, 9.6 and 10 bushels per acre, respectively, in plots of ½ square rod with 3 replications. Average yield of checks was 45.3 bushels an acre.

A preliminary method of measuring the relative efficiency of seed corn disinfectants. W. P. RALEIGH.

In studying seed-corn disinfectants it is often necessary to conduct many preliminary tests in order to ascertain the desirable concentrations and to eliminate undesirable dusts before making field trials. The following method has been found of much value. Treatments are made on units of 15 kernels each, placed in crystallizing dishes (10 × 5 cm.), and covered with 4 centimeters of washed sand. An equal amount of water is added to each culture at the beginning and later if necessary. The cultures may be placed either in the laboratory (22° to 25° C.) or in the greenhouse (16° to 20° C.). Both nearly-disease-free and diseased seed are used in these seed-treatment tests, the former to detremine injury and the latter to determine the effectiveness of the fungicides. The advantages of this method are: (1) ease of application at any time of year, and without the use of greenhouse or field space; (2) visibility of both roots and tops so that the effect of disease or injury by the disinfectant can be correlated with top growth at any rate; (3) ease of freeing the plants from the sand for final examination; (4) decrease in number of fungicides to be used in further experiments.

Transmission of potato spindle-tuber by grasshoppers (Locustidae). R. W. GOSS.

While aphids have been shown to transmit spindle-tuber they are not numerous enough in the potato sections of western Nebraska to account for the rapidity with which the disease sometimes spreads. Tests were therefore made with some of the more common insects occurring in potato fields. In 1925, out of 36 inoculations made using grasshoppers, from 1 to 10 in each test, as the transmitting agents, 8 resulted in typical spindle-tuber. In 1926, 29 infections were obtained from 64 inoculations. Single, double, and triple inoculations with the same grasshoppers also were tried. With larger numbers of insects and repeated inoculations the percentage of infection increased. Uncaged control plants always remained healthy and the possibility of uncontrolled field transmission by other means is negligible. Current season symptoms did not occur in many cases and the progeny were indexed in the greenhouse and planted in the field the following year to obtain these results. All insects were fed upon healthy plants before being used in the tests. In the 1926 experiments it was found that 5 of the 77 plants upon which grasshoppers were fed before being placed on spindle-tuber plants became infected. Apparently these insects were viruliferous when collected.

A new and destructive disease of the potato in Utah and its relation to the potato psylla. B. L. RICHARDS.

During the past season a new and destructive disease swept Utah potato fields, the west slope of Colorado, and later appeared in southern Idaho, Montana, and Wyoming. The rate of spread and the degree of damage indicate that the malady may become one of the most destructive diseases so far reported on the potato in this region. The early crop was most severely affected. Symptoms of the disease clearly differentiate it from any of the potato diseases thus far described. An upward rolling of the basal portion of young leaves constitute the first and most distinctive symptom. In the Bliss Triumph and Irish Cobbler this rolled portion becomes brilliantly colored, varying from light pinkish yellow to purple. The older leaves roll upward, turn yellow, and die. The axillary buds are stimulated into one or a combination of three types of growth; thick shoots which may exceed the leaf in length, aerial tubers, and rosettes of small and frequently highly colored leaves.

In Utah, Idaho, Montana, and Wyoming the potato Psylla (*Paratrioza cockerelli Sulc.*) was found associated with diseased plants, and subsequent experimental work

shows the disease to be induced in some way by the nymph of this insect, all the various symptoms of the disease noted in the field having been produced under controlled conditions in the greenhouse. Nymphs confined by gauze bags to a single lower or older leaf produce the early symptoms of the disease in remote portions of the plant in 9 days.

Because of the peculiar yellowness common to the disease in all varieties of potato so far studied, the writer suggests the name "yellows."

A preliminary report on the relationship of insect carriers to the development of tip and margin burn of irish potatoes. H. R. ROSEN.

Results of three years of experimental work at Fayetteville, Arkansas, with relatively large numbers of Irish potato plants placed under wire screens indicate a market correlation between vegetative growth and the use of such screens. Plants underneath the screens appear much larger, darker green, and are longer lived than unscreened plants. Quantitative studies of the chlorophyll content indicate that greater amounts of green coloring matter are present in the screened plants. When unscreened plants show relatively large proportions of tip- and margin-burning of the leaves, screened plants show little. Are these differences due to the effect of shade, of wind-breakage, or of insect control? Preliminary work appears to indicate that insect control, particularly of leaf hoppers, is at least partly concerned in these differences. This is suggested by recent studies, in which plants that were not completely covered with screens, and hence open to attack by leaf hoppers, showed the same amount of tip- and margin-burnnig as plants free from screens. Also, plants partially covered with wooden slats showed no superiority over unshaded ones.

The properties and behavior of potato rugose mosaic. JAMES JOHNSON.

With a view towards more satisfactory descriptions and classification of potato virus diseases, the properties of certain of these viruses are being determined. The rugose mosaic virus for instance will not yield good infection at a dilution much greater than 1 part of mosaic plant extract to 10 parts of water. The extracted virus loses its infectivity rapidly *in vitro*, approximately half of it being lost after 6 hours and all after 24 hours. The thermal death point of the rugose mosaic virus lies close to 43° C.; hence it is extremely sensitive to heat, as it is also to chemicals. Varieties of potatoes differ in their susceptibility to the virus. Bliss Triumph and Green Mountain being the most susceptible and Rural New Yorker the most resistant of the varieties tried. All attempts to pass this virus through bacterial proof filters have thus far failed. Other possible diagnostic features are also being studied. In general, the properties of the potato rugose mosaic virus are quite different from those of certain other potato viruses studied, such as leaf-rolling mosaic and spot necrosis.

The reaction and treatment of soils infested with Plasmodiophora brassicae Wor. F. L. WELLMAN.

It has been commonly believed that clubroot of crucifers is primarily dependent on the presence of an acid soil reaction, which if neutralized tends to reduce the amount of the disease. An extensive survey of seriously diseased fields shows reactions ranging from pH 5.0 to 7.7, in which most cases are close to neutral or slightly alkaline. Laboratory and field studies have demonstrated that increase of pH is not alone effective in inhibiting this disease. The amounts of different neutralizing substances required to inhibit the disease seem to depend upon the choice of reagents rather than the effect on pH. The pH was varied experimentally to alkalinity well above the high point found

in naturally infective soils without reducing severity of attack. Treatment of soils with different types of lime showed that 2 tons of calcium hydrate to the acre produced practical control of clubroot on a commercial scale. Air-slacked lime was found usable, but not satisfactory; while raw limestones, marls, and gypsums were ineffective.

A fusarium-resistant cabbage of Jersey Wakefield type. J. C. WALKER and F. L. WELLMAN.

There is a growing need in certain yellow-infested areas for an early-maturing resistant cabbage variety of the pointed head type. Initial selections were made in 1925 from surviving heads of the Jersey Wakefield variety on infested soil. These were grown to seed in the greenhouse during the following winter. Of the resulting progenies, tested in 1926, all segregated in the approximate ratio of 3 resistant to 1 susceptible. All poor type strains were discarded, and selections made from progenies of 4 original plants were grown to seed in 1926-27. In 1927, from 12 selfed progenies tested, 6 were secured which were homozygous for resistance, all showing a complete stand of healthy plants. The remaining 6 progenies again segregated at approximately 3 resistant to 1 susceptible. The results confirm earlier evidence that Fusarium-resistance in cabbage is a single dominant Mendelian character. From the homozygous resistant families of 1927 several were selected for multiplication. They are typical of Jersey Wakefield in all important characters including earliness.

The use of selection and selfing in improving Iacope cabbage. I. E. MELHUS and D. R. PORTER.

A strain of the yellows-resistant cabbage Iacope has been developed by selection and self pollination which proved immune when grown on severely infested land in 1927. This strain, designated as 15-23-2-S1-S1-S1, was subjected to a severe test for resistance to yellows for three growing seasons, and in 1927 every plant of 159 resisted the disease. The relative resistance of this strain since the original selection of Iacope from Copenhagen Market is as follows:

Generation	Percentage resistant	Index of resistance
1	33	206
2	45	145
3	85	304
4	95	452
5	100	455
6	100	323

This strain was compared with 12 other strains of Iacope and with Golden Acre and Copenhagen Market in 1927. Each strain was replicated four times on severely infested soil, and while this strain appeared immune, Golden Acre showed only 33 per cent resistance and Copenhagen Market only 32 per cent. This strain also possesses other desirable characteristics of a good early cabbage. It is the earliest of the Iacope strains, produces the largest percentage of marketable heads, and produces heads of medium size, uniform as to size and shape, and of uniform leaf characteristics and color.

Aphis transmission of cucumber mosaic. S. P. DOOLITTLE and M. N. WALKER.

Experiments on the transmission of cucumber mosaic by the melon aphis, *Aphis gossypii*, indicate that virus-free aphids can transmit the disease after feeding for five minutes on a mosaic plant. When transferred to healthy plants these aphids produced infection after an equally brief period of feeding. Experiments also indicate that the aphis loses its ability to transmit mosaic immediately after it first feeds on a healthy plant. In the latter experiments 1 to 10 aphids reared on mosaic plants were fed for 10 to 20 minutes on a healthy plant and immediately transferred to another healthy plant, where they remained. Infection occurred regularly on the first plants, but the second plants remained healthy in nearly every case. The aphids on the latter plants lived and multiplied, thus eliminating the possibility that the absence of infection was due to injury to the aphids. It appears that aphis transmission of mosaic results from the virus being carried into the plant tissues on the insect's proboscis and that the minute amount of virus thus carried is exhausted during the first feeding period. Aphids from mosaic plants do not transmit the disease after 6 to 8 hours' confinement in a test tube, this period being approximately the same as that during which the expressed juices of mosaic cucumber plants remain infectious.

Further evidence of resistance to cucumber mosaic in the Chinese cucumber. R. H. PORTER.

In July, 1927, 200 cucumber plants of the variety "Chinese Long" and 50 of the American Variety White Spine were inoculated in the greenhouse with the virus of cucumber mosaic. All plants were transplanted to the field two weeks after inoculation and were observed throughout the summer. None of the Chinese plants developed symptoms of mosaic but 75 per cent of the White Spine did. In this same field three rows of White Spine plants were grown from seed planted in hills. In these the incidence of mosaic due to natural infection was about 50 per cent, so that there was ample opportunity for natural as well as artificial infection to take place on the transplants of Chinese cucumbers. Furthermore, two and one-half rows were planted with the seed of the Chinese variety and in no case did any symptoms of mosaic develop. All the plants in this field were dusted while young with calcium arsenate and lime to restrict the injury from beetles but no effect was made to control plant lice.

Studies with the watermelon wilt, caused by Fusarium niveum E. F. S. D. R. PORTER.

Fusarium niveum E. F. S. may enter the host through root hairs, wounds, and epidermis of the hypocotyl. It produces 4 well defined symptoms on seedlings: (1) seedling rot, manifested by failure of the seedlings to emerge after germination; (2) damping-off, manifested by necrosis of cortical tissues at the soil surface causing the seedling to fall over; (3) stunting; (4) wilting, yellowing of the cotyledons, and eventual death. The organism grows most rapidly on potato dextrose agar between 24° and 32° C., its minimum being above 8° C. and its maximum above 35° C. It grows rapidly on a wide range of acid and alkaline media. The rate of growth on media of different pH values expressed in terms of the diameter of the colonies after 6 days is as follows:

pH 3.0	trace	pH 5.4	8.00 cm.
3.3	1.1 cm.	5.8	7.63
3.8	3.84	6.8	7.10
4.2	5.66	8.4	5.8
4.6	7.23		

The organism will remain alive (no visible growth) in an oxygen free chamber for at least 20 days. This fungus has been isolated from watermelon seeds secured from 12 sources and directly from seeds taken from melons attached to wilted vines. Cultures of *Fusarium niveum* secured from 5 states seem to be equally pathogenic to watermelon seedlings though differing slightly in physiological reactions in culture.

Infection in the field occurs most rapidly when seeds are planted about ½ inch above the inoculum. Inoculum placed above the seeds produces relatively little early infection.

Varietal resistance of watermelons to wilt (Fusarium niveum E. F. S.). D. R. PORTER.

During 1926 and 1927, 52 varieties of watermelons, 9 strains of African forage melons, the preserving citron, and 13 strains of Chinese melons were tested for wilt resistance on severely infested land in Iowa. All commercial varieties tested proved very susceptible. Infection varied from 75 to 100 per cent. The Conqueror was the most resistant. It lived about three weeks longer than the other varieties. Susceptibility among these varieties seems to vary with the soil and with moisture and temperature conditions.

Four of the 13 Chinese selections secured by R. H. Porter at Nanking, China, appeared to possess some resistance in 1927. Their resistance is expressed by the percentages 25, 28, 29, and 39 respectively; while commercial varieties used as controls showed 100 per cent infection. The preserving citron proved to be 82 per cent resistant in 1927 and two selections from African forage melons appeared to be immune. First generation hybrids seem to be as susceptible as the susceptible parent. Resistance in the F_2 generation varies with the resistant parent. African hybrids are much more resistant in the F_2 generation than are Conqueror hybrids. Flesh quality of the resistant parent appears to be dominant in the F_1 generation.

Some cytological phenomena in disease-resistant plants. J. DUFRENOY.

Certain species of *Phytophthora* live primarily in meristematic tissues in the cambial regions of roots and stems. As soon as the invading tips of the hyphae enter any part of the cambial tissue, they induce cells at some distance away to divide in a transverse plane and to form a pathologic cambial layer. This layer consists of two types of cells: (a) those on the side away from the infected tissues, containing large nuclei, dense cytoplasm and mitochondria; (b) those on the side toward the infected tissues, soon developing large vacuoles which accumulate tannoid compounds, fuse and crowd the cytoplasm and nuclei to the peripheries of the cells. If the fungus grows rapidly enough to invade the meristematic cells of the pathologic layer, it will continue to thrive, deriving its food from the cells and at the expense of their vital activity. If, on the contrary, the fungus fails to penetrate the pathologic layer before the cells have developed large vacuoles containing tannic compounds, it cannot obtain food and therefore starves. In this manner the lesion is checked.

Bacteriophage of Bacterium pruni. H. W. ANDERSON.

A bacteriophage of high potency was obtained from soil beneath infected peach trees. Ten successive filtrations were necessary to secure a bacteriophage sufficient to clear turbid cultures with certainty. A stock supply capable of clearing turbid suspensions of *B. pruni* when diluted to 10^{-6} and in some cases to 10^{-10} was finally obtained. Typical plaques were obtained with high dilutions on agar plates but secondary cultures almost always appeared after several days. One effort to get a bacteriophage from old infected peach leaves was unsuccessful.

The cycle of infection in apple blotch. EDWIN J. KOHL.

In an experimental block of 60 young Duchess apple trees at Vincennes, Indiana, in which cankers have been excised since 1922 and blotch sprays have been withheld from 1925 to 1927, counts of petiole infection were made in August, 1927, and the origin of infection determined. It was found that on 37 trees which showed infection and on which 12,330 leaves were examined, no infection was traced to cankers on 1926 wood; infection on 1615 leaves was traced to 72 cankers on 1925 wood; no infection was traced to 2 cankers on 1925 wood; infection on 35 leaves was traced to 6 cankers on 1924 wood; no infection was traced to cankers on 1923 or 1921 wood, of which two each were found present. This indicates the cycle of infection is at least two years in length.

By the use of potted trees it was found that infection at LaFayette, Ind., occurred during 18 out of 27 rain periods between 3 days and 7 weeks after petal-fall (May 7). At Mitchell, Ind., in 1927 infection occurred during 15 out of 17 rain periods between 5 days and 6 weeks after petal-fall (April 25).

Sporotrichum fruit spot of apple. MAX W. GARDNER.

In Grimes, Ben Davis, and Winesap apples grown in southern Indiana, a shallow surface spotting, apparently of fungous origin, has been found when the fruit was removed from cold storage. The lesions are more or less circular, slightly sunken, light brown spots, 5 to 15 mm. in diameter, with an indistinct margin and a silvery area at the center. The fungus which has been found constantly associated with these lesions closely resembles *Sporotrichum malorum* Kidd and Beaumont, a culture of which was obtained for comparison. An abundance of mycelium and spores is produced within the rotted tissues and the fungus can be readily isolated in pure culture. It grows rather slowly, but well at low temperatures. Inoculation tests have shown that the mycelium will invade the uninjured fruit and produce small lesions around the lenticels.

Studies of black root rot of apple. F. D. FROMME.

The occurrence of black root rot of apple in Virginia and other parts of the United States is discussed. The causative agent, **Xylaria mali** nom. nov., is an active parasite producing disease and death of trees of normal vigor. Death of 28 per cent of trees of the initial stand has occurred in one orchard at 25 years of age, and replant deaths have equalled 42 per cent at seven years of age. Stromata of the fungus are formed during late stages of disease. The fungus is also actively parasitic on Norway maple and Mahaleb cherry. It produces more limited infection on certain other deciduous trees. Some progress has been made in the attempts to control this disease through development of resistant root-stocks.

Factors important in the development of perithecia of Venturia inaequalis. E. E. WILSON.

The studies previously reported (PHYTOPATH. 16: 77) have been continued during the past two years. The data obtained further emphasize the relationship of the time of leaf-fall to the time of maturity of ascospores the following spring. In both years ascospores matured earlier in leaves which were placed on the ground in September than in those similarly placed later in the autumn. The delay in maturation did not, however, correspond to the delay in leaf-fall, as a delay in leaf-fall was followed by a shortening in the time between leaf-fall and maturation of ascospores.

Temperatures and moisture are cardinal factors in development of perithecia. The optimal temperature for their initiation was near 13° C., while the optimum for matura-

tion of ascospores was near 20° C. Growth of asci was found to occur more readily at 4° and 7° C. than maturation of ascospores. Development of the perithecia was sharply checked when the moisture of the leaf fell below an undefined limit. Perithecia matured more rapidly and normally in leaves which were alternately wet and dry than in those which were continuously wet.

Perithecia matured somewhat earlier in leaves of certain varieties than of others, although all varieties under observation produced mature perithecia in nature.

The type and abundance of leaf lesions appeared to bear a direct relationship to the quantity of perithecia produced. No evidence was found that perithecia were produced at points remote from lesions or that the fungus spread to uninfected leaves and there produced perithecia.

Fall applications of fungicides in relation to apple scab control. G. W. KEITT and E. E. WILSON.

The studies previously reported (PHYTOPATH. 17: 45) have been continued and extended. Severely infected apple foliage was sprayed after harvest but before leaf-fall with various materials, including calcium arsenite, Paris green, calcium silicofluoride, sodium silicofluoride, and certain proprietary preparations of chlorophenol mercury of different solubilities. Lime, Kayso, bordeaux mixture, and other materials were added to these chemicals in various combinations to modify their properties. Representative samples of untreated and treated leaves were overwintered and noted for the occurrence of perithecia of *Venturia inaequalis*. Numerous perithecia developed on untreated leaves. Comparatively little inhibition of their development seemed to result from applications of the silicofluorides or chlorophenol mercury. Marked reduction in perithecial development followed the use of calcium arsenite and Paris green, respectively, each in various combinations with other materials. In certain cases the treated leaves developed less than 10 per cent as many perithecia as the untreated. Calcium arsenite, unless modified by adding appropriate materials, caused considerable host injury. The results do not warrant specific recommendations for post-harvest fungicidal applications for apple scab control but they seem to give much promise of progress through attacking the fungus at a hitherto neglected, potentially vulnerable stage in its life-history.

Certain sulphur fungicides in the control of apple scab. J. M. HAMILTON and G. W. KEITT.

The following fungicides were tested for controlling apple leaf infection by ascospores of *Venturia inaequalis* (Cke.) Wint. in the greenhouse under controlled conditions; lime-sulphur (liquid), lime-sulphur plus lead arsenate, aerated lime-sulphur, sulphur-lead arsenate dust (90–10) and a commercial colloidal sulphur with and without lead arsenate. All these materials controlled the disease excellently when applied within 24 hours before inoculation. Considerable differences in effectiveness occurred when fungicides were applied after inoculation. Lime-sulphur, (1–40) plus lead arsenate (1–50) controlled leaf infection when applied after an infection period of 45 hours at 7°, or 30 hours at 24° C. Sulphur-lead arsenate dust (90–10) was much less effective, controlling leaf infection well when applied after a 12-hour infection period at 7° C., but not when applied later.

Lime-sulphur (1–40) plus lead arsenate (1–50) applied to scabbed leaves in the orchard prevented the germination of spores which were present and sharply inhibited production of spores from the treated lesions during a period of nine weeks, notwithstanding the occurrence of a series of rains. Sulphur-lead arsenate dust (90–10) gave like results until the first heavy rain, after which viable spores were produced.

Applications of lime-sulphur and sulphur dust, respectively, to comparatively small marked areas of the upper surface of apple leaves protected the entire upper surface from infection by naturally discharged ascospores.

Factors affecting the fungicidal property of sulphur. H. C. YOUNG and ROBERT WILLIAMS.

A part of this investigation is a continuation of the former work on the fungicidal property of sulphur. The results show that pentathionic acid is the toxic factor of sulphur. The test for this acid (the ammoniacal silver nitrate test given in Mellor's Modern Inorganic Chemistry) is positive for almost all sulphurs. The test is very simple, the color being first a brown and then slowly changing to black. It is peculiar that some other workers (English) have "failed to get a positive test upon repeated trials." The sulphide ion is the only sulphur compound that might give a positive test and this has been eliminated by other sulphide tests always being negative on ground or flowers of sulphur.

When sulphur is mixed with basic compounds such as sodium hydrate, potassium hydrate, or calcium hydrate, the salt of pentathionic acid which is not toxic to fungus spores is formed. However, as this salt is formed, more acid is produced and a general equilibrium is maintained. When sulphur was freed of its pentathionic acid and then placed in oxygen free Vantieghem cells it was not toxic to the spores of *Sclerotinia cinerea*. Lime added to sulphur reduced the effectiveness against apple scab in the field.

Heterothallism in the rust fungi. J. H. CRAIGIE.

The writer has made an experimental investigation of sex in the rust fungi and has obtained conclusive evidence that *Puccinia graminis* and *P. helianthi* are heterothallic. The sporidia are of two kinds, (+) and (−). A (+) sporidium gives rise to a (+) mycelium and a set of pycnia which produce (+) pycnospores. A (−) sporidium gives rise to a (−) mycelium and a set of pycnia which produce (−) pycnospores. When a (+) sporidium and a (−) sporidium are sown close together on a leaf, the (+) and (−) mycelia resulting therefrom intermingle and produce diploid aecia. When (+) pycnospores are brought into contact with a (−) pycnium, or (−) pycnospores with a (+) pycnium diploid aecia are produced on the under side of the pustule receiving the pycnospores within a few days of the transference.

The pycnium is to be regarded not as a spermagonium, producing non-functional spermatia, but as an active organ which develops either (+) or (−) pycnospores and attracts flies by means of which the pycnospores of one sex are carried to the pycnia of another sex.

Further observations on Corticium koleroga (Cke) v. Hohn. FREDERICK A. WOLF.

A recent paper contains an account of the thread-blight caused by *Corticium koleroga*, on citrous, pomaceous, and a variety of other hosts. The subsequent collections of the fungus on an isolated planting of *Citrus* in the Everglades leads to the belief that it is endemic to that section of Florida.

In another locality it was collected on coral tree, *Erythrina cristagalli*, and the stunted growth of the branches indicated that the fungus was present on this tree when it was introduced from Brazil. Privet *Ligustrum vulgare* and a species of climbing rose growing beneath the coral tree were also affected. Grapefruit and orange growing near were not attacked.

In another locality, the native persimmon, *Diospyros virginiana*, the cultivated persimmon, *D. kaki*, and fig, *Ficus carica*, were affected.

The failure of the fungus to spread to nearby plants of the pear, orange, and the grapefruit in nursery rows from an artificially inoculated pear tree indicates that wind borne basidiospores are of little consequence in the spread of the fungus. Little is known about the factors governing the distribution of *Corticium koleroga*.

Some investigations of Aspergilli by serological methods. TAKASHI MATSUMOTO.

Immune sera were prepared from several species of some groups of Aspergilli by means of ten successive intravenus inoculations of rabbits at intervals of about six days. The results obtained with agglutination experiments were rather unsuccessful, but the reactions by means of complement fixation have shown some significant relationships existing in those strains. They reveal a wide variation, but, as expected, the variation occurring between strains within the same species is not generally so wide as that existing between different species. Some results were also obtained by means of precipitation tests, but the complement fixation seems to be more promising for the serological studies of these particular fungi. It should be remembered, however, that the titre of the sera in these groups is much lower than that of ordinary pathogenic bacteria.

The mycorrhizal fungus of Vaccinium. K. D. DOAK.

During a survey of northern Indiana blueberry regions in 1925 and 1926, a non-pathogenic fungus was found associated in different soils with the roots of *Vaccinium corymbosum* Linn., *V. vacillans* Kalm. and *V. pennsylvanicum* Lam. This fungus developed as intracellular glomerulus masses and hyaline strands and a brownish, appressed external growth on roots in contact with organic particles, and produced an endotrophic mycorrhiza of the type previously described in *V. corymbosum*. A fungus resembling *Rhizoctonia* was isolated from fresh roots of *V. corymbosum* and *V. pennsylvanicum* by three methods. The mycelial characters in culture resembled those of the mycelium growing on roots. Fruiting bodies were not produced. The mycorrhiza was artificially produced by inoculating sterile seedlings with this *Rhizoctonia*.

Normal root and stem development did not depend upon the presence of the fungus, but a profuse growth of it around roots of seedlings was not detrimental. Seedlings transferred into unsterilized sphagnum peat and leaf mold grew more rapidly when roots already possessing the fungus were added. Although extensive development of the fungus often occurred in soil near living roots, there was no evidence of direct nutritive symbiosis.

An examination of Fusaria in the herbarium of the Pathological Collections, Bureau of Plant Industry, U. S. Department of Agriculture. C. D. SHERBAKOFF.

Three hundred and sixty one dry Fusarium specimens of the herbarium have been examined. Most of the original determinations had to be changed, but only two new species were found. Three new combinations seemed desirable. These were as follows:

Fusarium tumidum n. sp. Syn. *F. sarcochroum* (Desm.) Sacc. Krieger, Fungi saxonici, 2499; and Sydow, Mycotheca germanica, 1797, on heads of *Sarothamnus scoparius*, 1916.—The fungus resembles *F. culmorum* (W. G. Sm.) Sacc. but has much larger conidia (3–5-septate, 35–82 × 10 μ.).

Gibberella quinqueseptata n. sp. On *Cannabis sativa*, Pierceton, Indiana, 1915 coll. L. H. Dewey.—Differs from *G. saubinetii* mainly by 5(3)-septate ascospores.

Fusicoccum fraxini (Kabát et Bubák) n. com. Syn. *Fusarium fraxini* Kabát et Bubák. Fungi imperfecti exsiccati, 900, on dried branches of *Fraxinus excelsior*, Bohemia, 1910, 1912.

Ramularia carniformis (E. & T.) n. com. Syn. *Fusarium carniforme* E. & T., on *Tripsacum dactyloides*, herbarium S. M. Tracy, Stockwell, Miss., 1900.

Rhabdospora oxydendri (E. & E.) n. comb. Syn. *Fusarium oxydendri* E. and E., N. Am. Fungi, sec. ser. 3493. On bark of *Oxydendrum arboreum*, Nuttallburg, W. Va., 1896.

Two physiological forms of Ustilago striaeformis (Westd.) *Niessl.* W. H. DAVIS.

Ustilago striaeformis has been reported parasitic on 24 genera and 41 species of grasses. However, the problem of the physiologic specialization of this smut remains unsolved. This investigation was undertaken to determine whether physiologic forms occur in this smut or timothy (*Phleum pratense* L.) and on redtop (*Agrostis palustris Huds.*) Chlamydospores were collected from both hosts at several stations located in three states. The seedlings employed in the inoculations were incubated from seeds collected at five widely-distributed stations. The methods employed were those already described by the writer. The results were based on 15 series of inoculations, both reciprocal and multiple, in the field and greenhouse, during spring, summer, autumn, and winter. Inoculum taken from timothy infected timothy but not redtop, while inoculum removed from redtop infected but not timothy.

There are two physiologic forms of *Ustilago striaeformis* on these hosts: *U. striaeformis* P. F. 1 (which might also be designated as *phlei-pratensis*) which infects timothy and not redtop; *U. striaeformis* P. F. 2 (which might be designated as *agrostis-palustris*) which infects redtop but not timothy.

The occurrence of Aphanomyces cochlioides n. sp. on sugar beets in the United States. CHARLES DRECHSLER.

Isolations of fungi from sugar beet seedlings collected in fields near East Lansing and Saginaw, Michigan, late in June, 1927, revealed a species of Aphanomyces, **A. cochlioides** n. sp. among the several parasites causing damping-off and root-rot. In a well-watered experimental plot, it was responsible for more damage than all other organisms combined. The fungus is presumably identical with the form reported on beets from Germany as *A. laevis*. Entirely normal sexual reproductive structures, produced on suitable agar media, exhibit an oospore wall 1.5 to 2.0 μ thick, never 3 to 6 μ as given by Peters. The oogonial wall, unlike the thin envelope figured by DeBary, measures between 1.0 and 2.5 μ in thickness, and, while exhibiting fluctuations in this dimension from point to point, is not sculptured on its inner surface as prominently as in *A. euteiches*. The fungus differs from the pea parasite also in the frequent flat spiral disposition of the antheridial stalk on the oogonium, helicoid involvement of parts described for *A. helicoides* Minden, and present in a form isolated from oat roots, however, being generally absent. Contact relationship of elements supporting sex organs prevails much as in *A. euteiches* and in the conspicuously larger *A. raphani* Kendrick.

Paragynous antheridia of Phytophthora spp. DELMER COOPER.

The mycelium of *Phytophthora cactorum* (Lebert and Cohn) penetrates the unbroken epidermis of both apples and pears, by pushing apart the cork cells of the lenticles. A suspension of zoospores placed on the uninjured surface of the fruit also causes infection. The mycelium is intercellular in the host tissue and sends haustoria into the cells. As Rose and Lindegren have reported, oogonia and antheridia occur in the infected pear tissue but not in infected apple tissue. Both paragynous and amphigynous antheridia have been reported for this fungus, but in this study only paragynous antheridia have been found. Cultures of *P. erythroseptica* (Pethyb.), which is

described as having only amphigynous antheridia, were obtained from Pethybridge and from the Centraalbureau, Holland, but no amphigynous antheridia were found. *Phytophthora richardiae* (Buisman) and *P. terrestris* (Sherb.), which are described with amphigynous antheridia and a *Phytophthora sp.* from peony, have also been studied. Only paragynous antheridia have been found, and these are usually closely appressed at the base of the oogonia.

Studies on snapdragon rust, Puccinia antirrhini. E. B. MAINS and DOROTHY THOMPSON.

Urediniospores of *Puccinia antirrhini* germinate through a range of 0+ to 26+° C. with optimum germination around 10° C. While germination was obtained in solution of pH 3.6 to 8.0, the optimum was 6.0 to 6.2. While copper dust reduced germination to some extent, sulphur had the greatest fungicidal effect. Slaked lime also greatly reduced germination. A study of the effect of temperature on infection agreed with the results obtained with spore germination. Dusting with sulphur in the field almost completely controlled the rust, undusted plants dying before midsummer. Selections for resistance over a period of four years have resulted in the development of several lines showing marked resistance. While such lines are infected and mycelium developed to a considerable extent, the host cells often die before the rust is able to sporulate.

Studies upon the Fusarium wilt of china aster. L. R. JONES and REGINA S. RIKER.

The parasite *Fusarium conglutinans* var. *callistephi* is scarcely distinguishable from that of cabbage yellows, confirming Beach's statements, but reciprocal crosses showed each to be specific. The temperature relations were also very similar, both as determined for agar plate cultures and for disease development in soil temperature tanks ranging at 4° intervals from 12° to 32° C. No external smptoms of the disease appeared at 12° C. although the plants in infested soil weighed slightly less than the controls; wilt appeared at 16° C. and increased rapidly with rising temperature. Aster wilt was therefore favored by a slightly wider range of temperatures at the lower extreme than cabbage yellows. Development of wilt in the field was also accelerated by high temperature, as is cabbage yellows.

Considerable difference as to disease occurrence has been noted in commercial aster plantations on infested soils, both as between varieties and with individual plants of the same variety. Selections aiming to secure disease resistant strains have been conducted for the three seasons. These have included different colors of Giant Branching and Heart of France. The results are promising, the second generation selections showing in 1927 a much higher degree of resistance than did the commercial controls.

Progress report on the condition of bulbs and corms of ornamental plants offered for importation into Canada. F. L. DRAYTON.

Inspection of foreign importations of nursery stock, including bulbs, by officers of the Dominion Department of Agriculture revealed a highly unsatisfactory condition in many shipments. A study of the literature threw very little light on the economic importance of the various troubles, and the want of reliable information necessitated careful investigation into the nature and significance of these injuries. The bulbs and corms examined included the following: tulips, narcissi, hyacinths, iris (bulbous), snowdrops, gladioli for spring planting, *Gladiolus nanus* types for forcing, crocus, and freesias. The injuries were classified according to microscopic characters and cultured. Among the known pathogens observed were *Bacterium marginatum* McC., *Bact. hyacinthi* Wakker, *Septoria gladioli* Pass., *Botrytis tulipae* (Lib.) Hop., *Rhizoctonia tuliparum* (Kleb.) Whet. et J. M. Arthur, a *Sclerotium* sp. causing a dry rot of gladioli, and fre-

quently *Tylenchus dipsaci* Kuhn, one of the common nematodes affecting bulbs. In addition, a number of Fusaria and sclerotia-producing fungi, so far unidentified, have been isolated repeatedly from certain types of injuries. In many cases insect injury and improper handling, curing, etc., encouraged the development of saprophytic fungi, mites, etc., resulting in a more or less severe breakdown during storage and transportation.

Penicillium corm rot of gladioli. O. H. ELMER.

An undescribed storage rot of gladiolus corms was frequently observed in Iowa during the last two years. Infected corms develop dry rot lesions that extend to the heart and that finally include the entire corm. The lesions are brown on the outside and dark gray within. Throughout the rotted area, as well as on the surface, numerous grayish spherical sclerotia develop that average about ¾ mm. in diameter. Abundant blue conidial masses are frequently produced at the surface, especially under humid conditions on corms not completely mummified.

Laboratory studies have proved the causal organism to be a species of *Penicillium* (a new species which is being described elsewhere as *Penicillium gladioli* according to a letter from Dr. Charles Thom). Pure cultures were repeatedly obtained from marginal tissue plantings and from surface-sterilized sclerotia. On potato dextrose nutrient agar, conidial production is sparse but sclerotia are produced abundantly. Infections of corms in storage were obtained through wounds only. No infections were obtained on the corms of growing plants.

This disease of gladioli was the most common storage rot found in Iowa and was observed on corms of many varieties. The disease was, in addition, found in corm shipments from Minnesota and Indiana.

A corm rot of gladiolus caused by a Penicillium. LUCIA MCCULLOCH and CHARLES THOM.

A rot of gladiolus corms due to a sclerotium-forming species of *Penicillium* has been under observation since May, 1926. Both growing and stored corms become infected through even slight wounds. No infections have been secured by inoculations on uninjured corms. The dark brown, moderately porous rot invades the corm tissues rather rapidly at temperatures between 12 and 23° C. Most characteristic is the production of numerous sclerotia which appear both on the surface and in the interior of the attacked corms. The sclerotia are irregularly spherical; 140 to 540 μ in diameter; smooth; cream to light brown in color. On most culture media the fungus produces at room temperature a small area of dull blue green conidia in the center of the colony surrounded by an area of scanty white hyphae and numerous sclerotia in concentric zones. At temperatures above 20° C. the development of the blue-green conidia is very scanty, while at lower temperatures the conidia are abundant. The pathogenicity of the fungus has been proved by inoculation experiments and the connection of the sclerotia with the *Penicillium* has been definitely established. The fungus has been identified from corms grown in such widely separated regions as Holland, New Mexico, Canada, Kansas, and New York.

Mottle-leaf disease of beech. W. HOWARD RANKIN.

A large percentage of the beech in the general vicinity of Philadelphia have been affected for several years by a mottle-leaf disease of unknown cause. The incidence and severity of the disease do not appear to be correlated with site, age, ground water supply, or any atmospheric condition. No fungus or insect which seemed to have any causal relation to the disease has been observed above ground.

Mottle-leaf is apparent when the leaves develop in the spring. Yellow-green to whitish areas of indefinite outline are present, and these areas often die and turn brown. Seedlings and suckers in full shade often show severe symptoms. Borers and winter injury lead to stag-head and eventually death.

To determine if the lack of some mineral element was responsible, 10 typically affected trees were injected May 25–27, 1927. The trees received from 51 to 240 grams of magnesium nitrate and 10 to 47 grams of ferrous sulfate. The solution used contained 25.6 grams of magnesium nitrate and 5 grams of ferrous sulfate to each liter of water. The rate at which the injections were made varied from 3 liters in 2 hours and 45 minutes to 9.4 liters in 1 hour, 20–25 pounds pressure being applied to the solution.

No marked improvement in the chlorotic condition of the treated trees was noted during the summer.

The penetration of furfural in plant tissues. MARY F. HOWE and DONALD CATION.

Technical furfural painted on the stems of tomato plants from which a small area of the epidermis had been removed caused yellowing and flagging of the leaves and a shrivelling of the stems. High concentrations of furfural are markedly toxic to the green living stem and leaf tissue of herbaceous plants.

The rate of penetration of furfural, through the vascular bundles of the tomato stem, is six times as rapid as water. The furfural penetrates woody stems from four to nine times as rapidly as water. The variation in the rapidity of penetration depends largely upon the type of wood.

The amount of furfural absorbed by woody tissues, such as red oak, hard and soft maple, is from one and one-half to twice as much as the amount of water absorbed.

The amount of absorption by weight of varying solutions of furfural diluted with water (up to 7 per cent) gave no conclusive evidence that the water materially decreased the absorptive properties of furfural. The same size blocks of dry hickory, dry red oak, dry apple, and green apple absorbed less water in a given length of time than furfural, creosote, kerosene, and a creosote-furfural mixture.

An Actinomycete the cause of soil rot or pox in sweet potatoes. J. F. ADAMS.

During the past six years, investigations have been conducted on the cause of pox or soil rot of sweet potatoes. The results have shown that a species of *Actinomyces* is the pathogene rather than the fungus *Acrocystis batatas* reported by Halstead in 1890, or the slime mold *Cytospora batata* as reported by Elliott in 1916. This pathogene has been isolated from typical pox lesions as well as demonstrated to be present in the lesions by histological methods. Direct inoculations have shown this Actinomycete to be pathogenic on cut slices of sweet potato, emerging root points from fleshy, primary, and secondary roots, and stems of sprouts. Resulting lesions simulate those occurring under field conditions. This Actinomycete was also pathogenic on slices of white potato, beet, and turnip but gave negative results on carrot and dahlia. The optimum temperature in relation to growth and infection was found to range between 30° and 37° C. Slight growth or infection occurs under conditions of room temperature. Cultural and inoculation studies also included *A. poolensis* and *A. scabies*. Negative results followed with *A. poolensis*, while *A. scabies* was pathogenic on cut slices as well as rootlets of sweet potato and white potato.

Sweet potato stem rot prevented by treating stems and roots with bordeaux mixture. R. F. POOLE.

Killing of sweet potato plants in large numbers by the stem rot disease caused by *Fusarium batatatis* Wr. is a result of contamination during the interval of pulling and

resetting the plants. The appearance of the disease under natural field plantings was checked by inoculating plants with a pure culture, and the results were found to compare favorably. Inoculated plants were treated with several strengths of chemical disinfectants with the object of finding a substance which would prevent infection without injuring the plant. The susceptible Porto Rico and Yellow Jersey plants were used; the roots and stems were placed in a spore suspension from a three-day transfer, dipped into the chemical, and transplanted immediately in the field and in pots. A number of chemicals afforded no protection, and some caused severe injury to the plant. Others caused slight retardation of infection, while bordeaux mixture 4–4–50, and stronger, prevented infection in the field and greatly retarded the disease in pots. No attempt was made to control the disease when plants were already infected.

Comparison of various disinfectants in the treatment of sweet potatoes for black rot control: A progress report. O. C. BOYD.

Sweet potatoes of the Porto Rico variety were heavily inoculated with conidia, ascospores, and chlamydospores of the black rot fungus *Ceratostomella fimbriata*, then subjected to one of the treatments listed in table 1, after which the roots were dried and bedded. Each treatment included about 60 roots and was represented in 3 replications in the bed, while the uninoculated control included 138 roots in 5 replications, and the inoculated controls 284 in 13 replications. Soil conditions throughout the draw season

TABLE 1.—*The control of sweet potato black rot in the draw bed obtained by treating the seed with various disinfectants*

Treatment	Percentage of draws infected with black rot	Percentage of bedded roots infected with black rot	Average number of lesions per bedded potato
Uninoculated control	None	None	—
Inoculated control	25.8	96.5	3.8
Mercuric chloride 1–1000, 10 min.	16.2	56.0	2.2
do 2–1000, dip	9.2	56.1	2.0
Bayer Dipdust 1–20, 1 min.	18.0	72.4	2.3
Semesan Bel 1–20, dip	9.0	65.5	1.8
Formalin 3 pt.–50 gal., 10 min.; washed	12.2	81.7	2.0
do 5 pt.–50 gal., 1 min.; washed	13.5	62.0	1.6
Semesan 0.3% solution 10 min.	20.3	95.0	3.0
Semesan dust	18.0	70.7	2.6
du Pont No. 6 Bel 1–20, dip	18.9	74.1	2.4
do No. 21 Bel 1–20, dip	21.4	87.7	2.6
do No. 14 Bel 1–20, dip	21.4	91.4	3.4
do No. 2 Bel 1–20, dip	20.7	91.0	3.6
Semesan Jr. dust	23.2	71.7	2.1
Corona Coppercarb dust (20% copper)	9.2	82.1	2.2
Lucas-Kiltone bordo powder, dust (22% copper)	7.1	88.0	2.0
Colloidal sulphur dust (Niagara Sprayer Co.)	14.6	88.0	2.8

were favorable for the occurrence of black rot. The number of draws produced under the various treatments was not consistently related to the amount of black rot on either potatoes or draws. No appreciable injury resulted from any of the disinfectants, as measured by time of emergence of the draws.

Cytological studies of plant tissues affected with mosaic diseases. J. DUFRENOY.

Studies of living tissues, using neutral red in isotonic solution of cane sugar as a vital dye, and of tissues killed by the formalin and potassium bichromate fixative demonstrate that cells in the light areas differ from the normal green ones as follows: (a) the vacuoles do not stain readily with neutral red; and (b) mitochondria and plastids assume a swollen appearance, so that the chloroplasts, which show in the normal cell as a black network imbedding starch grains, look in the affected cells as if they were converted into spheres which stain a light grey with iron haematoxylin.

Monochromatic light photography in the study of mosaic diseases. FRANCIS O. HOLMES.

Monochromatic ultraviolet light photographs have been made of juices from plants having the following diseases: yellows of aster, strongly mottled mosaic of tobacco, ring spot of tobacco, rugose mosaic of potato, aucuba mosaic of potato, witches' broom of potato, and leaf roll of potato. No formed elements other than those found in normal plants were seen in the pictures of these representative viruses, although excellent resolution was obtained, and over six hundred photographs made.

During the past three years a cytological study has been made of the large intracellular bodies characteristic of Hippeastrum mosaic. It was hoped that they might be identified or at least better understood. The search for an included nucleus or nuclear material was unsuccessful. Chondriosomes were found distributed evenly through the mass of the intracellular bodies just as they are to be found in the host cell cytoplasm. This seemed to indicate that the inclusion is composed of living cytoplasm, whether native or foreign with respect to the host. Photographs of the inclusions with monochromatic blue light showed a characteristic granular structure in the mass of the intracellular body. This could also be seen in the living material.

Experiments with tomato streak. W. G. STOVER.

Streak has been induced by inoculating tomato plants with extract from mosaic tomato together with extract from potato plants with mild mosaic, rugose mosaic, leaf roll, or spindle tuber, and in some cases from apparently healthy potato plants. Streak was not induced when normal seedling potato plants were used as one source of inoculum. Streak was induced in tomato, however, if the potato seedlings had been previously inoculated with potato mosaic. Streak was also induced by inoculating tomato with juice from mosaic tomatoes together with juice from either tomato or black nightshade which had previously been inoculated with potato mosaic.

Streak is transmissible from streak-infected tomato through either tobacco or black nightshade back to tomato. Streak also developed in tomato plants inoculated from either tobacco or black nightshade which had previously been double inoculated with tomato mosaic and potato rugose mosaic. Streak developed in tomato plants inoculated with tomato mosaic and potato mosaic on widely separated dates.

The streak virus mixture may occur in any part of the diseased plant or may be absent from certain organs. The potato element becomes non-infective in a short time after the death of the affected tissue, while the tomato element may remain infective for some time.

Soil transmission of tomato mosaic and streak in the greenhouse. S. P. DOOLITTLE.

It has been found that the viruses of both tomato mosaic and streak will live for at least 70 days in greenhouse soils. These experiments were conducted in a house where both diseases were prevalent during the summer of 1927, using plants which had been grown in sterilized soil at another point. The plants were transplanted under cheesecloth cages in the house in question, the cages being without openings. Control plants on mosaic-free soil remained healthy. Infection occurred in all trials made to date and the experiments are being continued. In the field it has been found that the virus of tomato mosaic will live four to six weeks in the soil, but up to the present there has been no evidence of the overwintering of the virus in experiments where plants are protected by cages. Preliminary studies indicate that the streak of tomato produced by a mixed infection with the tobacco mosaic virus and either mosaic or healthy potato juices is not identical with much of the streak which is found occurring in the field and greenhouse.

Progress on experimental work with the transmission of bean mosaic. T. G. FAJARDO.

Artificial transmission. A modified leaf mutilation method has yielded from 80 to 100 per cent mosaic infection.

Insect transmission. Field and greenhouse cage experiments during 1926 and 1927 gave conclusive evidence of insect transmission of bean mosaic. Successful results were obtained with three species of mosaic-reared aphids and mealy-bugs. Negative results have thus far been obtained with leafhoppers, 12-spotted and striped cucumber beetles, red spider, thrips, tarnished plant bug, and white fly.

Soil transmission. Contact of roots on aerial parts and picking pods simultaneously between mosaic and healthy plants under cages failed to cause mosaic infection; transmission through soil likewise failed.

Seed transmission. Bean mosaic commonly overwinters in infected seed and in no other way thus far determined, no other hosts having been found. The percentage of seed infection varies widely with the variety, as high as 50 per cent being found in commercial seed of susceptible varieties. Plants grown from infected seed yielded in turn a higher percentage of infected seed than plants inoculated during their vegetative development, but in case of blossoming plants no infection of seed resulted in pods which had set previous to inoculation. On uniformly diseased mosaic plants there was less infection in late than in early set pods.

Virus diseases observed by the Allison V. Armour Expedition. H. H. MCKINNEY.

On the Canary Islands, mosaic was very prevalent on wild *Nicotiana glauca.* Three types of mosaic symptoms, a dark green, a light green, and a yellow, were found on this species. The light green type, which seems to be identical with the mosaic generally found on tobacco in the United States, was the most prevalent. Studies of these viruses on tobacco show that the yellow type can be isolated from yellow spots which are associated with the light green type. The dark green type shows excessive chlorophyl production, and the mottled areas are unusually large but few in number. Mosaic was found also on *Psoralea bituminosa,* wild garlic, and Irish potatoes.

In West Africa, mosaic was general on *Capsicum sp.* and on *Manihot esculenta,* which is an important fruit plant. In some cases mosaic seemed to be a limiting factor in its production. Yellow and green types of mosaic were found on three species of Cucurbitaceae and on several other plants.

Wild grasses were flourishing in the Cameroons, and sugar-cane was growing in all the Colonies visited, but no grass mosaic was found.

Further studies on the host range of aster yellows. L. O. KUNKEL.

During the past year the known host range of aster yellows has been extended by the experimental transmission of the disease to 21 species in 13 different families of plants. Transmission was accomplished in all cases by means of the leafhopper, *Cicadula sexnotata* Fall. Most of the new hosts are cultivated flowering plants. Aster yellows was carried to plants in five families from which susceptible species have not previously been reported. The disease has now been experimentally transmitted to more than 70 species in 28 different families of plants. Although aster yellows has a very wide host range, many species closely related to susceptible ones are immune. *Plantago major* L. is susceptible, but *P. lanceolata* L., though one of the favorite host plants of the aster leafhopper, is immune. *Centauria imperialis* Hort. is one of the most susceptible species, but *C. cyanus* L. does not become infected.

It has been demonstrated by transmission experiments that aster yellows is distinct from witches' broom of potatoes and from a yellows disease of boneset (*Eupatorium perfoliatum* L.) which is widely distributed throughout the Middle West.

Further studies on the attenuation of plant viruses. JAMES JOHNSON.

The attenuation of the ordinary tobacco mosaic virus by the exposure of newly inoculated plants to a constant temperature of 35–37° C. for 10 days has been previously reported. Continued studies on this subject show that little or no observable attenuation can be secured at temperatures below 34° C. with an exposure of 15 days. At this temperature a milder degree of attenuation was secured than can be obtained with a 15-day exposure at 38° C. Some of these attenuated viruses have remained attenuated after ten serial transfers through tobacco or after storing *in vitro* for several months. The tobacco mosaic virus has also been attenuated by means of bubbling air and oxygen through the virus extract for several weeks. The same virus has also been secured in a naturally attenuated form from several soils in which it had overwintered. The cucumber mosaic virus on tobacco has also been attenuated by exposure to a temperature of 37° C. for 10 days. Attenuation of viruses is rather sporadic and may not be secured in every case by any of these methods. Attempts to attenuate the potato rugose mosaic virus in a similar manner were unsuccessful.